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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICANT:	DEBECKER	
SERIAL NO.:	10/792,193	EXAMINER:
FILED:	MARCH 3, 2004	ART UNIT:
TITLE:	FIBRE-REINFORCED PRESSURE VESSEL AND METHOD OF MANUFACTURING FIBRE-REINFORCED PRESSURE VESSEL	CONFIRMATION NO.:

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

DECLARATION OF PROFESSOR ADRIAAN BEUKERS

Sir:

1. I am a professor and hold a chair in the design of composite materials in the faculty of Aerospace Engineering at Delft University of Technology in the Netherlands. Exhibit A details my professional experience.

2. I have been involved in the field of fibre wound pressure vessels since the early 1990's. From my experience in the field and to the best of my knowledge, fibre wound pressure vessels known in the period from 1993 until the date of the present invention routinely used a matrix material in combination with fibre filaments which substantially prevented movement of the fibre filaments with respect to one another.

3. I have read Murphy, U.S. Patent No. 5,526,994. While this document does not expressly state that the disclosed fibre-wound pressure vessel includes a matrix material that would prevent movement of the fibre filaments with respect to one another, as one of skill in the art, I am of the opinion that the invention described in this document would in fact have such a matrix material. I am further of the opinion that one skilled in the art at the time of the invention

37 CFR 1.8
CERTIFICATE OF MAILING
I hereby certify that this correspondence is being deposited with the United States Postal Service as first class mail in an envelope addressed to: Mail Stop Amendment, Assistant Commissioner for Patents, Washington, D.C. 20231 on August 20, 2004.

Signature: Elizabeth A. McArthur
Name: Elizabeth A. McArthur

described in this document would have understood it to have included a matrix material preventing movement of the fibre filaments.

4. More particularly, Murphy discloses a load carrying "filament winding 14" at column 2, line 19. Subsequently, claims 1-4 recite a "filament-wound pressure vessel"; and claims 7-8 recite a "filament wound pressure vessel." To one of skill in the art prior to February 2000, these references to "filament wound" would mean filaments previously impregnated with a matrix material ("dry winding") or impregnated during the winding ("wet winding"). See Exhibit B, a Glossary of Terms, specifically the definition of "filament winding"; "dry winding" and "wet winding."

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that willful false statements and the like so made are punishable by fine or imprisonment, or both, under ' 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Date: August 11th 2004 By:

C:\TEMP\Temporary Internet Files\Declaration of Beukers.doc

DELFT UNIVERSITY OF TECHNOLOGY
FACULTY OF AEROSPACE ENGINEERING

Exhibit A

Curriculum Vitae

Discipline Group

Production Technology of Composite Materials and Structures

Program Research, Development and Design of (laminated) fiber reinforced polymer composite materials, structures and manufacturing techniques

---

1. Personal

Name Prof. Ir. Adriaan Beukers
Date of birth 1946 December 20

2. Academic degrees

MSc in Aerospace Engineering, Delft University, 1977

Title of Thesis

Stresses around a pin-loaded hole in elastically orthotropic plates

3. Employment at DUT

Present position: Professor on Composite Materials and Structures, Anthony van Leeuwenhoek Chair, since 1999 April 1

Former position(s): Associate Professor of Composite Materials and Structures, 1987 - 1999 April 1

4. Former/other positions elsewhere

Fokker Aircraft, Structures Department, P.E. for composite aircraft structures; development, analysis and certification, 1979 - 1987 April 1.

KU Leuven, visiting professor European Course on Composites and Polymers, since 1993

Center for Lightweight Structures, TNO-TU Delft, director research and development, since 1996

Doshisha University, Kyoto, Japan Visiting Fellow researcher of the Composites Centre, 2004-

5. Memberships of scientific and professional societies

Memberships of the Steering Committees/ Advisory Board/s Scientific committees:

European Post Graduate Education in Polymer and Composite Engineering,, Leuven.
International Training Institute for Materials Science, ITIMS, Hanoi.
European Conference on Textiles, TEXCOMP.
European Conference on Composite Materials, ECCM.
Centrum Uitvoering Research en Regelgeving, , CUR Gouda.
Board of Directors, Euro Enaer Den Helder.
Board of Directors, Advanced Lightweight Engineering, Delft.
Board of Directors, K3C Provincie Noord Holland.
Voorzitter van de Onderwijs Commissie LR, Delft.
Member of the Composites Committee, SAMPE Japan Chapter.
Member of NWM Belgium and STW Netherlands to appraise textile, composites and polymer R&D proposals.
Advisory Board of International Course Advanced Industrial Design Engineering, Delft.
Member of the Airbus Technology Review of Airbus France, Toulouse

6. Honors and awards

National Award for Industrial Design 'Theo Limperg', The Netherlands Design Institute, 1997, Amsterdam.
Antonie van Leeuwenhoek honorary chair, TUDelft, 1999.
Ultra-Light Pressure Vessel for LPG, A. Beukers , Th. de Jong, USP 6,176,386, PCT/NL96/00437, ALB, Best Invention of the year 2000 , Dutch Industrial Design Award ., ID-NL.
The "George Taylor (of Australia) Prize 2003' awarded to A. Beukers, M.J.L. van Tooren en C.A.J.R. Vermeeren for their article "Aircraft structures in the century ahead", published in "The Aeronautical Journal of the Royal Aeronautical Society"

Exhibit B

Volume 1

ENGINEERED MATERIALS HANDBOOK

COMPOSITES

ASM INTERNATIONAL

ENGINEERED MATERIALS HANDBOOK™

Volume 1

COMPOSITES

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Engineered Materials Handbook is a collective effort involving hundreds of technical specialists. It brings together in one book a wealth of information from world-wide sources to help scientists, engineers, and technicians solve current and long-range problems.

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Glossary of Terms

Harry E. Pebly, Army Armament Research & Development Center

A

A-basis. The "A" mechanical property value is the value above which at least 99% of the population of values is expected to fall, with a confidence of 95%. Also called A-allowable. See also *B-basis*, *S-basis*, and *typical-basis*.

abhesive. A material that resists adhesion. A film or coating applied to surfaces to prevent sticking, heat sealing, and so on, for example, a parting agent or mold release agent.

ablation. The degradation, decomposition, and erosion of a material caused by high temperature, pressure, time, percent oxidizing species, and velocity of gas flow. A controlled loss of material to protect the underlying structure.

ablative plastic. A material that absorbs heat (with a low material loss and char rate) through a decomposition process (pyrolysis) that takes place at or near the surface exposed to the heat.

ABL bottle. An internal pressure test vessel about 460 mm (18 in.) in diameter and 610 mm (24 in.) long used to determine the quality and properties of the filament-wound material in the vessel.

absorption. The penetration into the mass of one substance by another. The process whereby energy is dissipated within a specimen placed in a field of radiant energy. The capillary or cellular attraction of adherend surfaces to draw off the liquid adhesive film into the substrate.

accelerated test. A test procedure in which conditions are increased in magnitude to reduce the time required to obtain a result. To reproduce in a short time the deteriorating effect obtained under normal service conditions.

accelerator. A material that, when mixed with a catalyst or a resin, will speed up the chemical reaction between the catalyst and the resin (either in polymerizing of resins or vulcanization of rubbers). Also called promoter.

acoustic emission. A measure of integrity of a material, as determined by sound emission when a material is stressed. Ideally, emissions can be correlated with defects and/or incipient failure.

acrylic plastic. A thermoplastic polymer made by the polymerization of esters of acrylic acid and its derivatives. Its full name is polymethyl methacrylate. See also *polymethyl methacrylate*.

activation. The (usually) chemical process of making a surface more receptive to bonding to a coating or an encapsulating material.

activator. See *accelerator*.

addition polymerization. A chemical reaction in which simple molecules (monomers) are added to each other to form long-chain molecules (polymers) without forming by-products.

additive. Any substance added to another substance, usually to improve properties, such as plasticizers, initiators, light stabilizers, and flame retardants. See also *filler*.

adherend. A body that is held to another body, usually by an adhesive. A detail or part prepared for bonding.

adhesion. The state in which two surfaces are held together at an interface by mechanical or chemical forces or interlocking action or both.

adhesion, mechanical. See *mechanical adhesion*.

adhesion promoter. A coating applied to a substrate before it is coated with an adhesive, to improve the adhesion of the plastic. Also called primer.

adhesive. A substance capable of holding two materials together by surface attachment. Adhesive can be in film, liquid, or paste form.

adhesive, anaerobic. See *anaerobic adhesive*.

adhesive, cold-setting. See *cold-setting adhesive*.

adhesive, contact. See *contact adhesive*.

adhesive failure. Rupture of an adhesive bond such that the separation appears to be at the adhesive-adherend interface.

adhesive film. A synthetic resin adhesive, with or without a film carrier fabric, usually of the thermosetting type, in the form of a thin film of resin, used under heat and pressure as an interleaf in the production of bonded structures.

adhesive, gap-filling. See *gap-filling adhesive*.

adhesive, heat-activated. See *heat-activated adhesive*.

adhesive, heat-sealing. See *heat-sealing adhesive*.

adhesive, hot-melt. See *hot-melt adhesive*.

adhesive, hot-setting. See *hot-setting adhesive*.

adhesive, intermediate temperature setting. See *intermediate temperature setting adhesive*.

adhesive joint. The location at which two adherends or substrates are held together with a layer of adhesive. The general area of contact for a bonded structure.

adhesive, pressure-sensitive. See *pressure-sensitive adhesive*.

adhesive strength. Strength of the bond between an adhesive and an adherend.

adhesive, structural. See *structural adhesive*.

admixture. The addition and homogeneous dispersion of discrete components, before cure.

adsorption. The adhesion of the molecules of gases, dissolved substances, or liquids in more or less concentrated form, to the surfaces of solids or liquids with which they are in contact. A concentration of a substance at a surface or interface of another substance.

afterbake. See *postcure*.

aggregate. A hard, coarse material usually of mineral origin used with an epoxy binder (or other resin) in plastic tools. Also used in flooring or as a surface medium.

aging. The effect on materials of exposure to an environment for an interval of time. The process of exposing materials to an environment for an interval of time.

air-bubble void. Air entrapment within and between the plies of reinforcement or within

dicular to the warp. Also called fill, filling yarn, or woof.

weld line. The mark visible on a finished part made by the meeting of two flow fronts of plastic material during molding. Also called weld mark or flow line.

weld mark. See *flow line*.

wet installation. A bolted joint in which sealant is applied to the head and shank of the fastener so that after assembly a seal is provided between the fastener and the elements being joined.

wet lay-up. A method of making a reinforced product by applying the resin system as a liquid when the reinforcement is put in place.

wet-out. The condition of an impregnated roving or yarn in which substantially all voids between the sized strands and filaments are filled with resin.

wet strength. The strength of an organic matrix composite when the matrix resin is saturated with absorbed moisture, or is at a defined percentage of absorbed moisture less than saturation. (Saturation is an equilibrium condition in which the net rate of absorption under prescribed conditions falls essentially to zero).

wetting. The spreading, and sometimes absorption, of a fluid on or into a surface.

wet winding. In filament winding, the process of winding glass on a mandrel in which the strand is impregnated with resin just before contact with the mandrel. See also *dry winding*.

whisker. A short single crystal fiber or filament used as a reinforcement in a matrix. Whisker diameters range from 1 to 25 μm (40 to 980 μin.), with aspect ratios between 100 and 15 000.

wind angle. The angular measure in degrees between the direction parallel to the filaments and an established reference. In filament-wound structures it is the convention to measure the wind angle with reference to the centerline through the polar bosses, that is, the axis of rotation.

winding pattern. The total number of individual circuits required for a winding path to begin repeating by laying down immediately adjacent to the initial circuit. A regularly recurring pattern of the filament path after a certain number of mandrel revolutions, leading eventually to the complete coverage of the mandrel.

winding tension. In filament winding or tape wrapping, the amount of tension on the reinforcement as it makes contact with the mandrel.

woof. See *weft*.

work hardening. Increase in resistance to further deformation with continuing distortion. Hardening and strengthening of a metal or alloy caused by the strain energy absorbed from prior deformation.

working life. The period of time during which a liquid resin or adhesive, after mixing with catalyst, solvent, or other compounding ingredients, remains usable. See also *gelation time* and *pot life*.

woven fabric. A material (usually a planar structure) constructed by interlacing yarns, fibers, or filaments, to form such fabric patterns as plain, harness satin, or leno weaves.

woven roving. A heavy glass fiber fabric made by weaving roving or yarn bundles.

wrinkle. A surface imperfection in laminated plastics that has the appearance of a crease or fold in one or more outer sheets of the paper, fabric, or other base, which has been pressed in. Also occurs in vacuum bag molding when the bag is improperly placed, causing a crease.

X

***x*-axis.** In composite laminates, an axis in the plane of the laminate which is used as the 0° reference for designating the angle of a lamina.

***xy*-plane.** In composite laminates, the reference plane parallel to the plane of the laminate.

Y

yarn. An assemblage of twisted filaments, fibers, or strands, either natural or manufactured, to form a continuous length that is suitable for use in weaving or interweaving into textile materials.

yarn bundle. See *bundle*.

yarn, plied. See *plied yarn*.

***y*-axis.** In composite laminates, the axis in the plane of the laminate that is perpendicular to the *x*-axis. Contrast with *x-axis*.

yield point. The first stress in a material, less than the maximum attainable stress, at which the strain increases at a higher rate than the stress. The point at which permanent deformation of a stressed specimen begins to take place. Only materials that exhibit yielding have a yield point.

yield strength. The stress at the yield point. The stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. The lowest stress at which a material undergoes plastic deformation. Below this stress, the material is elastic; above it, the material is viscous. Often defined as the stress needed to produce a specified amount of plastic deformation (usually a 0.2% change in length).

Young's modulus. The ratio of normal stress to corresponding strain for tensile or compressive stresses less than the proportional limit of the material. See also *modulus of elasticity*.

Z

z-axis. In composite laminates, the reference axis normal to the plane of the laminate.

zero bleed. A laminate fabrication procedure that does not allow loss of resin during cure. Also describes prepreg made with the amount of resin desired in the final part, such that no resin has to be removed during cure.

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the radii of curvature are adjusted to balance the stresses along the filaments with the pressure loading.

balanced laminate. A composite laminate in which all laminae at angles other than 0° and 90° occur only in ± pairs (not necessarily adjacent) and are symmetrical around the centerline. See also *symmetrical laminate*.

balanced twist. An arrangement of twists in a combination of two or more strands that does not cause kinking or twisting on themselves when the yarn produced is held in the form of an open loop.

band density. In filament winding, the quantity of fiberglass reinforcement per inch of band width, expressed as strands (or filaments) per inch.

band thickness. In filament winding, the thickness of the reinforcement as it is applied to the mandrel.

band width. In filament winding, the width of the reinforcement as it is applied to the mandrel.

Barcol hardness. A hardness value obtained by measuring the resistance to penetration of a sharp steel point under a spring load. The instrument, called the Barcol impressor, gives a direct reading on a 0 to 100 scale. The hardness value is often used as a measure of the degree of cure of a plastic.

bare glass. Glass, such as yarns, rovings, and fabrics, from which the sizing or finish has been removed. Also, such glass before the application of sizing or finish.

barrier coat. An exterior coating applied to a composite wound structure to provide protection.

barrier film. The layer of film used to permit removal of air and volatiles from a composite lay-up during cure while minimizing resin loss.

batch. In general, a quantity of material formed during the same process or in one continuous process and having identical characteristics throughout. Also called a lot.

batt. Felted fabrics. Structures built by the interlocking action of compressing fibers, without spinning, weaving, or knitting.

B-basis. The "B" mechanical property value is the value above which at least 90% of the population of values is expected to fall, with a confidence of 95%. See also *A-basis*, *S-basis*, and *typical-basis*.

bearing area. The diameter of the hole times the thickness of the material. The cross-section area of the bearing load member on the sample.

bearing strain. The ratio of the deformation of the bearing hole, in the direction of the applied force, to the pin diameter. Also, the stretch or deformation strain for a sample under bearing load.

bearing strength. The maximum bearing stress that can be sustained. Also, the bearing stress at that point on the stress-strain curve where the tangent is equal to the bearing stress divided by *n*% of the bearing hole diameter.

bearing stress. The applied load in pounds divided by the bearing area. Maximum bearing stress is the maximum load in pounds sustained by the specimen during the test, divided by the original bearing area.

bending-twisting coupling. A property of certain classes of laminates that exhibit twisting curvatures when subjected to bending moments.

bias fabric. Warp and fill fibers at an angle to the length of the fabric.

biaxial load. A loading condition in which a laminate is stressed in two different directions in its plane. A loading condition of a pressure vessel under internal pressure and with unrestrained ends.

biaxial winding. In filament winding, a type of winding in which the helical band is laid in sequence, side by side, with crossover of the fibers eliminated.

bidirectional laminate. A reinforced plastic laminate with the fibers oriented in two directions in its plane. A cross laminate. See also *unidirectional laminate*.

billet. A small ingot of nonferrous metal.

binder. The resin or cementing constituent (of a plastic compound) that holds the other components together. The agent applied to fiber mat or preforms to bond the fibers before laminating or molding.

bismaleimide (BMI). A type of polyimide that cures by an addition rather than a condensation reaction, thus avoiding problems with volatiles formation, and which is produced by a vinyl-type polymerization of a prepolymer terminated with two maleimide groups. Intermediate in temperature capability between epoxy and polyimide.

bladder. An elastomeric lining for the containment of hydroproof or hydroburst pressurization medium in filament-wound structures.

blanket. Fiber or fabric plies that have been laid up in a complete assembly and placed on or in the mold all at one time (flexible bag process). Also, the form of bag in which the edges are sealed against the mold.

bleeder cloth. A woven or nonwoven layer of material used in the manufacture of composite parts to allow the escape of excess gas and resin during cure. The bleeder cloth is removed after the curing process and is not part of the final composite.

bleeding. The removal of excess resin from a laminate during cure. The diffusion of color out of a plastic part into the surrounding surface or part.

bleedout. The excess liquid resin that migrates to the surface of a winding. Primarily occurs in filament winding.

bloom. A visible local exudation or finish change on the surface of a plastic. Bloom can be caused by a lubricant or plasticizer or by atmospheric contamination.

BMC. See *bulk molding compound*.

BMI. See *bismaleimide*.

body putty. A pastelike mixture of plastic resin (polyester or epoxy) and talc used in repair of metal surfaces, such as auto bodies.

bond strength. The amount of adhesion between bonded surfaces. The stress required to separate a layer of material from the base to which it is bonded, as measured by load/bond area. See also *peel strength*.

boron fiber. A fiber produced by vapor deposition of elemental boron, usually onto a tungsten filament core, to impart strength and stiffness.

braiding. Weaving of fibers into a tubular shape instead of a flat fabric, as for graphite fiber reinforced golf club shafts.

branched polymer. In molecular structure of polymers, a main chain with attached side chains, in contrast to a linear polymer.

breaking extension. The elongation necessary to cause rupture of a test specimen. The tensile strain at the moment of rupture.

breaking factor. The breaking load divided by the original width of a test specimen, expressed in lb/in.

breaking length. A measure of the breaking strength of yarn. The length of a specimen whose weight is equal to the breaking load.

breakout. Fiber separation or break on surface plies at drilled or machined edges.

breather. A loosely woven material that serves as a continuous vacuum path over a part but is not in contact with the resin.

breathing. The opening and closing of a mold to allow gas to escape early in the molding cycle. Also called degassing; sometimes called bumping in phenolic molding.

bridging. Condition in which fibers do not move into or conform to radii and corners during molding, resulting in voids and dimensional control problems.

broad goods. Fiber woven to form fabric up to 1270 mm (50 in.) wide. It may or may not be impregnated with resin and is usually furnished in rolls of 25 to 140 kg (50 to 300 lb).

B-stage. An intermediate stage in the reaction of certain thermosetting resins in which the material softens when heated and is plastic

performance under prescribed conditions of test.

thermal expansion molding. A process in which elastomeric tooling details are constrained within a rigid frame to generate consolidation pressure by thermal expansion during the curing cycle of the autoclave molding process.

thermal stress cracking. Crazing and cracking of some thermoplastic resins, resulting from overexposure to elevated temperatures. See also *stress cracking*.

thermoforming. Forming a thermoplastic material after heating it to the point where it is soft enough to be formed without cracking or breaking reinforcing fibers.

thermogravimetric analysis (TGA). The study of the mass of a material under various conditions of temperature and pressure.

thermoplastic. Capable of being repeatedly softened by an increase of temperature and hardened by a decrease in temperature. Applicable to those materials whose change upon heating is substantially physical rather than chemical and that in the softened stage can be shaped by flow into articles by molding or extrusion.

thermoplastic polyesters. A class of thermoplastic polymers in which the repeating units are joined by ester groups. The two important types are (1) polyethylene terephthalate (PET), which is widely used as film, fiber, and soda bottles; and (2) polybutylene terephthalate (PBT), primarily a molding compound.

thermoset. A plastic that, when cured by application of heat or chemical means, changes into a substantially infusible and insoluble material.

thermosetting polyesters. A class of resins produced by dissolving unsaturated, generally linear, alkyd resins in a vinyl-type active monomer such as styrene, methyl styrene, or diallyl phthalate. Cure is effected through vinyl polymerization using peroxide catalysts and promoters or heat to accelerate the reaction. The two important commercial types are (1) liquid resins that are cross-linked with styrene and used either as impregnants for glass or carbon fiber reinforcements in laminates, filament-wound structures, and other built-up constructions, or as binders for chopped-fiber reinforcements in molding compounds, such as sheet molding compound (SMC), bulk molding compound (BMC), and thick molding compound (TMC); and (2) liquid or solid resins cross-linked with other esters in chopped-fiber and mineral-filled molding compounds, for example, alkyd and diallyl phthalate.

thin-layer chromatography (TLC). A micro type of chromatography in which a thin layer of special absorbent is applied to a glass plate, a drop of a solution of the material being investigated is applied to an edge, and that side of the plate is then dipped in an appropriate solvent. As the solvent travels up the thin layer, it selectively separates the molecules present in the material being investigated.

thixotropic (thixotropy). Concerning materials that are gel-like at rest but fluid when agitated. Having high static shear strength and low dynamic shear strength at the same time. To lose viscosity under stress.

thread. See *fiber*.

thread count. The number of yarns (threads) per inch in either the lengthwise (warp) or crosswise (fill or weft) direction of woven fabrics.

TLC. See *thin-layer chromatography*.

tolerance. The guaranteed maximum deviation from the specified nominal value of a component characteristic at standard or stated environmental conditions.

tooling resin. Resins that have applications as tooling aids, coreboxes, prototypes, hammer forms, stretch forms, foundry patterns, and so forth. Epoxy and silicone are common examples.

tool side. The side of the part that is cured against the tool (mold or mandrel).

torsion. Twisting stress.

torsional stress. The shear stress on a transverse cross section caused by a twisting action.

toughness. A property of a material for absorbing work. The actual work per unit volume or unit mass of material that is required to rupture it. Toughness is proportional to the area under the load-elongation curve from the origin to the breaking point.

tow. An untwisted bundle of continuous filaments. Commonly used in referring to man-made fibers, particularly carbon and graphite, but also glass and aramid. A tow designated as 140K has 140 000 filaments.

tracer. A fiber, tow, or yarn added to a prepreg for verifying fiber alignment and, in the case of woven materials, for distinguishing warp fibers from fill fibers.

transfer molding. Method of molding thermosetting materials in which the plastic is first softened by heat and pressure in a transfer chamber and then forced by high pressure through suitable sprues, runners, and gates into the closed mold for final shaping and curing.

transition, first order. See *first-order transition*.

transition temperature. The temperature at which the properties of a material change. Depending on the material, the transition change may or may not be reversible.

transversely isotropic. Term describing a material exhibiting a special case of orthotropy in which properties are identical in two orthotropic dimensions but not the third. Having identical properties in both transverse directions but not in the longitudinal direction.

transverse strain. The linear strain in a plane perpendicular to the loading axis of a specimen.

true strain. The natural logarithm of the ratio of gage length at the moment of observation to the original gage length for a body subjected to an axial force.

true stress. The stress along the axis calculated on the actual cross section at the time of observation instead of the original cross-sectional area. Applicable to tension and compression testing.

turns per inch (tpi). A measure of the amount of twist produced in a yarn, tow, or roving during its processing history. Also, the lead rate of a hoop layer at a specified band width. See also *twist*.

twist. The spiral turns about its axis per unit of length in a yarn or other textile strand. Twist may be expressed as turns per inch (TPI), and so forth. *S* and *Z* refer to direction of twist, in reference to whether the twist direction conforms to the middle-section slope of the particular letter.

twist, balanced. See *balanced twist*.

typical-basis. The typical property value is an average value. No statistical assurance is associated with this basis.

U

ultimate elongation. The elongation at rupture.

ultimate tensile strength. The ultimate or final (highest) stress sustained by a specimen in a tension test. Rupture and ultimate stress may or may not be the same.

ultrasonic testing. A nondestructive test applied to materials for the purpose of locating internal flaws or structural discontinuities by the use of high-frequency reflection or attenuation (ultrasonic beam).

ultraviolet (UV). Zone of invisible radiations beyond the violet end of the spectrum of visible radiations. Since UV wavelengths are shorter than visible wavelengths, their photons have more energy, enough to initiate some chemical reactions and to degrade most plastics, particularly aramids.

ultraviolet (UV) stabilizer. Any chemical compound that, when admixed with a thermoplastic resin, selectively absorbs UV rays.

unbond. An area within a bonded interface between two adherends in which the intended bonding action failed to take place, or where

cloth. See *woven fabric* and *nonwoven fabric*.

co-curing. The act of curing a composite laminate and simultaneously bonding it to some other prepared surface, or curing together an inner and outer tube of similar or dissimilar fiber-resin combination after each has been wound or wrapped separately. See also *secondary bonding*.

coefficient of elasticity. The reciprocal of Young's modulus in a tension test. See also *compliance*.

coefficient of expansion. A measure of the change in length or volume of an object, specifically measured by the increase in length or volume of an object per unit length or volume.

coefficient of friction. A measure of the resistance to sliding of one surface in contact with another surface.

coefficient of thermal expansion (CTE). The change in length or volume per unit length or volume produced by a 1° rise in temperature.

cohesion. The propensity of a single substance to adhere to itself. The internal attraction of molecular particles toward each other. The ability to resist partition of itself. The force holding a single substance together.

cohesive failure. Failure of an adhesive joint occurring primarily in an adhesive layer.

cohesive strength. Intrinsic strength of an adhesive.

coin test. Using a coin to tap a laminate in different spots, listening for a change in sound, which would indicate the presence of a defect. A surprisingly accurate test in the hands of experienced personnel.

coke. Carbonaceous residue resulting from the pyrolysis of pitch.

cold flow. The distortion that takes place in materials under continuous load at temperatures within the working range of the material without a phase or chemical change. See also *creep*.

cold-setting adhesive. A synthetic resin adhesive capable of hardening at normal room temperature in the presence of a hardener.

collet. A rigid, lateral container for the mold-forming material. A dam, a restriction box. The drive wheel that pulls glass fibers from the bushing. A forming tube is placed on the collet, and a package of strand is wound up on the tube. A metal band, ferrule, collar, or flange, often used to hold a tool or workpiece.

collimated. Rendered parallel.

collimated roving. Roving that has been made using a special process (usually parallel wound), so that the strands are more parallel than in standard roving.

colloidal. A state of suspension in a liquid medium in which extremely small particles are suspended and dispersed but not dissolved.

compaction. The application of a temporary vacuum bag and vacuum to remove trapped air and compact the lay-up.

compatibility. The ability of two or more substances combined with one another to form a homogeneous composition of useful plastic properties; for example, the suitability of a sizing or finish for use with certain general resin types. Nonreactivity or negligible reactivity between materials in contact.

complex dielectric constant. The vectorial sum of the dielectric constant and the loss factor.

complex shear modulus. The vectorial sum of the shear modulus and the loss modulus.

complex Young's modulus. The vectorial sum of Young's modulus and the loss modulus. Analogous to the complex dielectric constant.

compliance. Tensile compliance: the reciprocal of Young's modulus. Shear compliance: the reciprocal of shear modulus. Also, a term used in the evaluation of stiffness and deflection.

composite material. A combination of two or more materials (reinforcing elements, fillers, and composite matrix binder), differing in form or composition on a macroscale. The constituents retain their identities; that is, they do not dissolve or merge completely into one another although they act in concert. Normally, the components can be physically identified and exhibit an interface between one another.

compound. The intimate admixture of a polymer with other ingredients, such as fillers, softeners, plasticizers, reinforcement, catalysts, pigments, or dyes. A thermoset compound usually contains all the ingredients necessary for the finished product, while a thermoplastic compound may require subsequent addition of pigments, blowing agents, and so forth.

compression molding. A mold that is open when the material is introduced and that shapes the material by the pressure of closing and by heat.

compressive modulus. Ratio of compressive stress to compressive strain below the proportional limit. Theoretically equal to Young's modulus determined from tensile experiments.

compressive strength. The ability of a material to resist a force that tends to crush or buckle. The maximum compressive load sustained by a specimen divided by the original cross-sectional area of the specimen.

compressive stress. The normal stress caused by forces directed toward the plane on which they act.

condensation polymerization. A chemical reaction in which two or more molecules combine, with the separation of water or some other simple substance. If a polymer is formed, the process is called polycondensation. See also *polymerization*.

conditioning. Subjecting a material to a prescribed environmental and/or stress history before testing.

conductivity. Reciprocal of volume resistivity. The electrical or thermal conductance of a unit cube of any material (conductivity per unit volume).

consolidation. In metal matrix or thermoplastic composites, a processing step in which fiber and matrix are compressed by one of several methods to reduce voids and achieve desired density.

constituent. In general, an element of a larger grouping. In advanced composites, the principal constituents are the fibers and the matrix.

contact adhesive. An adhesive that is apparently dry to the touch and which will adhere to itself simultaneously upon contact. An adhesive applied to both adherends and allowed to become dry, which develops a bond when the adherends are brought together without sustained pressure.

contact molding. A process for molding reinforced plastics in which reinforcement and resin are placed on a mold. Cure is either at room temperature using a catalyst-promoter system or by heating in an oven, without additional pressure.

contact pressure resins. Liquid resins that thicken or polymerize on heating, and, when used for bonding laminates, require little or no pressure.

contaminant. An impurity or foreign substance present in a material or environment that affects one or more properties of the material, particularly adhesion.

continuous filament yarn. Yarn formed by twisting two or more continuous filaments into a single, continuous strand.

copolymer. A long-chain molecule formed by the reaction of two or more dissimilar monomers. See also *polymer*.

core. The central member, usually foam or honeycomb, of a sandwich construction to which the faces of the sandwich are attached or bonded. The central member of a plywood assembly. A channel in a mold for circulation of heat transfer media. A device on which prepreg is wound.

core crush. A collapse, distortion, or compression of the core.

core depression. A localized indentation or gouge in the core.

cored mold. A mold incorporating passages for electrical heating elements, steam, or water.

mined by burning off or dissolving the organic sizing; known as loss on ignition.

skein. A continuous filament, strand, yarn, or roving, wound up to some measurable length and usually used to measure various physical properties.

skin. The relatively dense material that may form the surface of a cellular plastic or of a sandwich.

skirt. The extension of a motorcase from the tangency plane, used for interstage connections, usually wound or laid up as an integral part of the case.

slenderness ratio. The unsupported effective length of a uniform column divided by the least radius of gyration of the cross-sectional area.

slip angle. The angle at which a tensioned fiber will slide off a filament-wound dome. If the difference between the wind angle and the geodesic angle is less than the slip angle, fiber will not slide off the dome. Slip angles for different fiber-resin systems vary and must be determined experimentally.

sliver. A number of staple or continuous-filament fibers aligned in a continuous strand without twist. Pronounced "slyver." See also *strand*.

slurry preforming. Method of preparing reinforced plastic preforms by wet processing techniques similar to those used in the pulp molding industry. For example, glass fibers suspended in water are passed through a screen that passes the water but retains the fibers in the form of a mat.

SMC. See *sheet molding compound*.

***S-N* diagram.** A plot of stress (*S*) against the number of cycles to failure (*N*) in fatigue testing. A log scale is normally used for *N*. For *S*, a linear scale is often used, but sometimes a log scale is used here, too. Also, a representation of the number of alternating stress cycles a material can sustain without failure at various maximum stresses.

softening range. The range of temperatures in which a plastic changes from a rigid to a soft state. Actual values will depend on the test method. Sometimes erroneously referred to as softening point.

solvation. The process of swelling, gelling, or dissolving a resin by a solvent or plasticizer.

specific gravity. The density (mass per unit volume) of any material divided by that of water at a standard temperature.

specific heat. The quantity of heat required to raise the temperature of a unit mass of a substance 1° under specified conditions.

specific properties. Material properties divided by the material density.

SPF. See *superplastic forming*.

splay. A fanlike surface defect near the gate on a part.

splice. The joining of two ends of glass fiber yarn or strand, usually by means of an air-drying adhesive.

sprayed metal molds. Molds made by spraying molten metal onto a master until a shell of predetermined thickness is achieved. The shell is then removed and backed up with plaster, cement, casting resin, or other suitable material. Used primarily as a mold in the sheet forming process.

spray-up. Technique in which a spray gun is used as an applicator tool. In reinforced plastics, for example, fibrous glass and resin can be simultaneously deposited in a mold. In essence, roving is fed through a chopper and ejected into a resin stream that is directed at the mold by either of two spray systems. In foamed plastics, fast-reacting urethane foams or epoxy foams are fed in liquid streams to the gun and sprayed on the surface. On contact, the liquid starts to foam.

spring constant. The number of pounds required to compress a spring or specimen 25 mm (1 in.) in a prescribed test procedure.

sprue. A single hole through which thermoset molding compounds are injected directly into the mold cavity.

spun roving. A heavy low-cost glass or aramid fiber strand consisting of filaments that are continuous but doubled back on themselves.

stabilization. In carbon fiber forming, the process used to render the carbon fiber precursor infusible prior to carbonization.

stacking sequence. A description of a laminate that details the ply orientations and their sequence in the laminate.

staging. Heating a premixed resin system, such as in a prepreg, until the chemical reaction (curing) starts, but stopping the reaction before the gel point is reached. Staging is often used to reduce resin flow in subsequent press molding operations.

standard deviation. A measure of dispersion of data from the average. The root mean square of the individual deviation from the average.

staple fibers. Fibers of spinnable length manufactured directly or by cutting continuous filaments to short lengths (usually 12.7 to 50 mm, or 1/2 to 2 in. long; 1 to 5 denier).

starved area. An area in a plastic part that has an insufficient amount of resin to wet out the reinforcement completely. This condition may be due to improper wetting, impregnation, or resin flow; excessive molding pressure; or improper bleeder cloth thickness.

starved joint. An adhesive joint that has been deprived of the proper film thickness of adhesive due to insufficient adhesive spreading or to the application of excessive pressure during the lamination process.

static fatigue. Failure of a part under continued static load. Analogous to creep rupture failure in metals testing, but often the result of aging accelerated by stress.

static modulus. The ratio of stress to strain under static conditions. It is calculated from static stress-strain tests, in shear, compression, or tension. Expressed in force per unit area.

static stress. A stress in which the force is constant or slowly increasing with time, for example, test of failure without shock.

stiffness. A measure of modulus. The relationship of load and deformation. The ratio between the applied stress and resulting strain. A term often used when the relationship of stress to strain does not conform to the definition of Young's modulus. See also *stress-strain*.

stops. Metal pieces inserted between die halves. Used to control the thickness of a press-molded part. Not a recommended practice, because the resin will receive less pressure, which can result in voids.

storage life. The period of time during which a liquid resin, packaged adhesive, or prepreg can be stored under specified temperature conditions and remain suitable for use. Also called shelf life.

strain. Elastic deformation due to stress. Measured as the change in length per unit of length in a given direction, and expressed in percentage or mm/mm (in./in.).

strain, axial. See *axial strain*.

strain gage. Device to measure strain in a stressed material based on the change in electrical resistance.

strain, initial. See *initial strain*.

strain relaxation. Reduction in internal strain over time. Similar molecular processes occur as in creep, except that the body is constrained.

strain, residual. See *residual strain*.

strain, shear. See *shear strain*.

strain, transverse. See *transverse strain*.

strain, true. See *true strain*.

strand. Normally an untwisted bundle or assembly of continuous filaments used as a unit, including slivers, tows, ends, yarn, and so forth. Sometimes a single fiber or filament is called a strand.

strand count. The number of strands in a plied yarn. The number of strands in a roving.

strand integrity. The degree to which the individual filaments making up the strand or end are held together by the applied sizing.

Used for continuous filaments. The lower the denier, the finer the yarn.

densification process. Consolidation of a loose or bulky material.

deposition. The process of applying a material to a base by means of vacuum, electrical, chemical, screening, or vapor methods, often with the assistance of a temperature and pressure container.

design allowables. Statistically defined (by a test program) material property allowable strengths, usually referring to stress or strain. See also *A-basis*, *B-basis*, *S-basis*, and *typical basis*.

desizing. The process of eliminating sizing, which is generally starch, from gray (also greige) goods before applying special finishes or bleaches (for yarn such as glass or cotton). Also, removing lubricant size following weaving of a cloth.

desorption. A process in which an absorbed material is released from another material. Desorption is the reverse of absorption, adsorption, or both.

devitrification. The formation of crystals (seeds) in a glass melt, usually occurring when the melt is too cold. These crystals can appear as defects in glass fibers.

D-glass. A high boron content glass made especially for laminates requiring a precisely controlled dielectric constant.

dielectric. A nonconductor of electricity. The ability of a material to resist the flow of an electrical current.

dielectric constant. The ratio of the capacitance of an assembly of two electrodes separated solely by a plastic insulating material to its capacitance when the electrodes are separated by air. See also *complex dielectric constant*.

dielectric curing. The curing of a synthetic thermosetting resin by the passage of an electric charge (produced from a high frequency generator) through the resin.

dielectric heating. The heating of materials by dielectric loss in a high-frequency electrostatic field.

dielectric loss. A loss of energy evidenced by the rise in heat of a dielectric placed in an alternating electric field.

dielectric monitoring. A means of tracking the cure of thermosets by changes in their electrical properties during material processing.

dielectric strength. The property of an insulating material that enables it to withstand electric stress. The average potential per unit thickness at which failure of the dielectric material occurs.

dielectrometry. Use of electrical techniques to measure the changes in loss factor (dissipation) and in capacitance during cure of the resin in a laminate.

differential scanning calorimetry (DSC). Measurement of the energy absorbed (endotherm) or produced (exotherm) as a resin system is cured. Also detects loss of solvents and other volatiles.

differential thermal analysis (DTA). An experimental analysis technique in which a specimen and a control are heated simultaneously and the difference in their temperatures is monitored. The difference in temperature provides information on relative heat capacities, presence of solvents, changes in structure (that is, phase changes, such as melting of one component in a resin system), and chemical reactions. See also *differential scanning calorimetry*.

dimensional stability. Ability of a plastic part to retain the precise shape to which it was molded, cast, or otherwise fabricated.

disbond. An area within a bonded interface between two adherends in which an adhesion failure or separation has occurred. Also, colloquially, an area of separation between two laminae in the finished laminate (in this case, the term delamination is normally preferred). See also *debond*.

displacement angle. In filament winding, the advancement distance of the winding ribbon on the equator after one complete circuit.

dissipation factor, electrical. See *electrical dissipation factor*.

distortion. In fabric, the displacement of fill fiber from the 90° angle (right angle) relative to the warp fiber. In a laminate, the displacement of the fibers (especially at radii), relative to their idealized location, due to motion during lay-up and cure.

doctor blade or bar. A straight piece of material used to spread resin, as in application of a thin film of resin for use in hot melt prepregging or for use as an adhesive film. Also called paste metering blade.

doily. In filament winding, the planar reinforcement applied to a local area between windings to provide extra strength in an area where a cut-out is to be made, for example, port openings. Usually placed at the knuckle joints of cylinder to dome.

dome. In filament winding, the portion of a cylindrical container that forms the spherical or elliptical shell ends of the container.

doubler. In filament winding, a local area with extra wound or fabric reinforcement, wound integrally with the part, or wound separately and fastened to the part.

doubler. See *tabs*.

draft. The taper or slope of the vertical surfaces of a mold designed to facilitate removal of molded parts.

draft angle. The angle of a taper on a mandrel or mold that facilitates removal of the finished part.

drape. The ability of a fabric or prepreg to conform to a contoured surface.

drawn fiber. Fiber with a certain amount of orientation imparted by the drawing process by which it was formed.

dry laminate. A laminate containing insufficient resin for complete bonding of the reinforcement. See also *resin-starved area*.

dry lay-up. Construction of a laminate by the layering of preimpregnated reinforcement (partly cured resin) in a female mold or on a male mold, usually followed by bag molding or autoclave molding.

dry winding. A term used to describe filament winding using preimpregnated roving, as differentiated from wet winding, where unimpregnated roving is pulled through a resin bath just before being wound onto a mandrel. See also *wet winding*.

DSC. See *differential scanning calorimetry*.

DTA. See *differential thermal analysis*.

ductility. The amount of plastic strain that a material can withstand before fracture. Also, the ability of a material to deform plastically before fracturing.

dwell. A pause in the application of pressure or temperature to a mold, made just before it is completely closed, to allow the escape of gas from the molding material. In filament winding, the time that the traverse mechanism is stationary while the mandrel continues to rotate to the appropriate point for the traverse to begin a new pass. In a standard autoclave cure cycle, an intermediate step in which the resin matrix is held at a temperature below the cure temperature for a specified period of time sufficient to produce a desired degree of staging. Used primarily to control resin flow.

dynamic modulus. The ratio of stress to strain under vibratory conditions (calculated from data obtained from either free or forced vibration tests, in shear, compression, or elongation).

E

edge distance ratio. The distance from the center of the bearing hole to the edge of the specimen in the direction of the principal stress, divided by the diameter of the hole.

edge joint. A joint made by bonding the edge faces of two adherends.

E-glass. A family of glasses with a calcium aluminoborosilicate composition and a maximum alkali content of 2.0%. A general-purpose fiber that is most often used in reinforced plastics, and is suitable for electrical laminates because of its high resistivity. Also called electric glass.

resin impregnation bath and through a shaping die, where the resin is subsequently cured.

pyrolysis. With respect to fibers, the thermal process by which organic precursor fiber materials, such as rayon, polyacrylonitrile (PAN), and pitch, are chemically changed into carbon fiber by the action of heat in an inert atmosphere. Pyrolysis temperatures can range from 800 to 2800 °C (1470 to 5070 °F), depending on the precursor. Higher processing graphitization temperatures of 1900 to 3000 °C (3450 to 5430 °F) generally lead to higher modulus carbon fibers, usually referred to as graphite fibers. During the pyrolysis process, molecules containing oxygen, hydrogen, and nitrogen are driven from the precursor fiber, leaving continuous chains of carbon.

Q

quasi-isotropic laminate. A laminate approximating isotropy by orientation of plies in several or more directions.

R

random pattern. A winding with no fixed pattern. If a large number of circuits is required for the pattern to repeat, a random pattern is approached. A winding in which the filaments do not lie in an even pattern.

reaction injection molding (RIM). A process for molding polyurethane, epoxy, and other liquid chemical systems. Mixing of two to four components in the proper chemical ratio is accomplished by a high-pressure impingement-type mixing head, from which the mixed material is delivered into the mold at low pressure, where it reacts (cures).

reinforced plastics. Molded, formed, filament-wound, tape-wrapped, or shaped plastic parts consisting of resins to which reinforcing fibers, mats, fabrics, and so forth, have been added before the forming operation to provide some strength properties greatly superior to those of the base resin.

reinforced reaction injection molding (RRIM). A reaction injection molding with a reinforcement added. See also *reaction injection molding*.

reinforcement. A strong material bonded into a matrix to improve its mechanical properties. Reinforcements are usually long fibers, chopped fibers, whiskers, particulates, and so forth. The term should not be used synonymously with filler.

relaxation time. The time required for a stress under a sustained constant strain to diminish by a stated fraction of its initial value.

relaxed stress. The initial stress minus the remaining stress at a given time during a stress-relaxation test.

release agent. A material that is applied in a thin film to the surface of a mold to keep the resin from bonding to the mold. See also *mold release agent*. Also called parting agent.

release film. An impermeable layer of film that does not bond to the resin being cured. See also *separator*.

residual gas analysis (RGA). The study of residual gases in vacuum systems using mass spectometry.

residual strain. The strain associated with residual stress.

residual stress. The stress existing in a body at rest, in equilibrium, at uniform temperature, and not subjected to external forces. Often caused by the forming and curing process.

resilience. The ratio of energy returned, on recovery from deformation, to the work input required to produce the deformation (usually expressed as a percentage). The ability to regain an original shape quickly after being strained or distorted.

resin. A solid or pseudosolid organic material, usually of high molecular weight, that exhibits a tendency to flow when subjected to stress. It usually has a softening or melting range, and fractures conchoidally. Most resins are polymers. In reinforced plastics, the material used to bind together the reinforcement material; the matrix. See also *polymer*.

resin content. The amount of resin in a laminate expressed as either a percentage of total weight or total volume.

resin pocket. An apparent accumulation of excess resin in a small, localized section visible on cut edges of molded surfaces, or internal to the structure and nonvisible. See also *resin-rich area*.

resin-rich area. Localized area filled with resin and lacking reinforcing material. See also *resin pocket*.

resin-starved area. Localized area of insufficient resin, usually identified by low gloss, dry spots, or fiber showing on the surface.

resin system. A mixture of resin and ingredients such as catalyst, initiator, diluents, and so forth, required for the intended processing and final product.

resin transfer molding (RTM). A process whereby catalyzed resin is transferred or injected into an enclosed mold in which the fiberglass reinforcement has been placed.

resistivity. The ability of a material to resist passage of electrical current either through its bulk or on a surface.

reverse helical winding. In filament winding, as the fiber delivery arm traverses one circuit, a continuous helix is laid down, reversing direction at the polar ends. In contrast to biaxial, compact, or sequential winding. The fibers cross each other at definite equators, the number depending on the helix. The minimum region of crossover is three.

reverse impact test. A test in which one side of a sheet of material is struck by a pendulum or falling object, and the reverse side is inspected for damage.

RGA. See *residual gas analysis*.

rheology. The study of the flow of materials, particularly plastic flow of solids and the flow of non-Newtonian liquids. The science treating the deformation and flow of matter.

rib. A reinforcing member designed into a plastic part to provide lateral, horizontal, hoop, or other structural support.

RIM. See *reaction injection molding*.

rise time. In urethane foam molding, the time between the pouring of the urethane mix and the completion of foaming.

Rockwell hardness. A value derived from the increase in depth of an impression as the load on an indenter is increased from a fixed minimum value to a higher value and then returned to the minimum value. Indenters for the Rockwell test include steel balls of several specific diameters and a diamond cone penetrator having an included angle of 120° with a spherical tip having a radius of 0.2 mm (0.0070 in.). Rockwell hardness numbers are always quoted with a prefix representing the Rockwell scale corresponding to a given combination of load and indenter, for example, HRC 30.

room-temperature curing adhesive. An adhesive that sets (to handling strength) within an hour at temperatures from 20 to 30 °C (68 to 86 °F) and later reaches full strength without heating.

room-temperature vulcanizing (RTV). Vulcanization or curing at room temperature by chemical reaction; usually applies to silicones and other rubbers.

roving. A number of yarns, strands, tows, or ends collected into a parallel bundle with little or no twist.

roving ball. The supply package offered to the winder, consisting of a number of ends or strands wound to a given outside diameter onto a length of cardboard tube. Usually designated by either fiber weight or length in yards.

roving cloth. A textile fabric, coarse in nature, woven from rovings.

RRIM. See *reinforced reaction injection molding*.

RTM. See *resin transfer molding*.

RTV. See *room-temperature vulcanizing*.

rubber. Cross-linked polymers with glass transition temperature below room temperature, which exhibit highly elastic deformation and have high elongation.

rupture. A cleavage or break resulting from physical stress. Work of rupture. The integral of the stress-strain curve between the origin and the point of rupture.

a short single-crystal fiber or filament made from a wide variety of materials, with diameters ranging from 1 to 25 μm (40 to 1400 μin.) and aspect ratios (a measure of length) between 100 and 15 000. Fibers can be continuous or specific short lengths (discontinuous), normally no less than 3.2 mm (1/8 in.).

fiber content. The amount of fiber present in a composite. This is usually expressed as a percentage volume fraction or weight fraction of the composite.

fiber count. The number of fibers per unit width of ply present in a specified section of a composite.

fiber diameter. The measurement (expressed in hundred thousandths) of the diameter of individual filaments.

fiber direction. The orientation or alignment of the longitudinal axis of the fiber with respect to a stated reference axis.

fiberglass. An individual filament made by drawing molten glass. A continuous filament is a glass fiber of great or indefinite length. A staple fiber is a glass fiber of relatively short length, generally less than 430 mm (17 in.), the length related to the forming or spinning process used.

fiberglass reinforcement. Major material used to reinforce plastic. Available as mat, roving, fabric, and so forth, it is incorporated into both thermosets and thermoplastics.

fiber pattern. Visible fibers on the surface of laminates or molding. The thread size and weave of glass cloth.

fiber-reinforced plastic (FRP). A general term for a composite that is reinforced with cloth, mat, strands, or any other fiber form.

fiber show. Strands or bundles of fibers that are not covered by plastic and that are at or above the surface of a composite.

fiber wash. Splaying out of woven or nonwoven fibers from the general reinforcement direction. Fibers are carried along with bleeding resin during cure.

filament. The smallest unit of a fibrous material. The basic units formed during drawing and spinning, which are gathered into strands of fiber for use in composites. Filaments usually are of extreme length and very small diameter, usually less than 25 μm (1 mil). Normally filaments are not used individually. Some textile filaments can function as a yarn when they are of sufficient strength and flexibility.

filament winding. A process for fabricating a composite structure in which continuous reinforcements (filament, wire, yarn, tape, or other), either previously impregnated with a matrix material or impregnated during the winding, are placed over a rotating and removable form or mandrel in a prescribed way to meet certain stress conditions. Generally the shape is a surface of revolution and may or may not include end closures. When the required number of layers is applied, the wound form is cured and the mandrel removed.

fill. Yarn oriented at right angles to the warp in a woven fabric.

filler. A relatively inert substance added to a material to alter its physical, mechanical, thermal, electrical, and other properties or to lower cost or density. Sometimes the term is used specifically to mean particulate additives. See also *inert filler*.

fillet. A rounded filling or adhesive that fills the corner or angle where two adherends are joined.

filling yarn. The transverse threads or fibers in a woven fabric. Those fibers running perpendicular to the warp. Also called weft.

film adhesive. A synthetic resin adhesive, usually of the thermosetting type, in the form of a thin, dry film of resin with or without a paper or glass carrier.

finish. A mixture of materials for treating glass or other fibers. It contains a coupling agent to improve the bond of resin to the fiber, and usually includes a lubricant to prevent abrasion, as well as a binder to promote strand integrity. With graphite or other filaments, it may perform any or all of the above functions.

first-order transition. A change of state associated with crystallization or melting in a polymer.

flame resistance. Ability of a material to extinguish flame once the source of heat is removed. See also *self-extinguishing resin*.

flame retardants. Certain chemicals that are used to reduce or eliminate the tendency of a resin to burn.

flammability. Measure of the extent to which a material will support combustion.

flash. That portion of the charge which flows from or is extruded from the mold cavity during the molding. Extra plastic attached to a molding along the parting line, which must be removed before the part is considered finished.

flexibilizer. An additive that makes a finished plastic more flexible or tough. See also *plasticizer*.

flexible molds. Molds made of rubber or elastomeric plastics, used for casting plastics. They can be stretched to remove cured pieces with undercuts.

flexural modulus. The ratio, within the elastic limit, of the applied stress on a test specimen in flexure to the corresponding strain in the outermost fibers of the specimen.

flexural strength. The maximum stress that can be borne by the surface fibers in a beam in bending. The flexural strength is the unit resistance to the maximum load before failure by bending, usually expressed in force per unit area.

flow. The movement of resin under pressure, allowing it to fill all parts of a mold. The gradual but continuous distortion of a material under continued load, usually at high temperatures; also called creep.

flow line. A mark on a molded piece made by the meeting of two flow fronts during molding. Also called striae, weld mark, or weld line.

flow marks. Wavy surface appearance of an object molded from thermoplastic resins, caused by improper flow of the resin into the mold.

fluted core. An integrally woven reinforcement material consisting of ribs between two skins in a unitized sandwich construction.

foamed plastics. Resins in sponge form, flexible or rigid, with cells closed or interconnected and density over a range from that of the solid parent resin to 0.030 g/cm^3. Compressive strength of rigid foams is fair, making them useful as core materials for sandwich constructions. Also, a chemical cellular plastic, the structure of which is produced by gases generated from the chemical interaction of its constituents.

foaming agent. Chemicals added to plastics and rubbers that generate inert gases on heating, causing the resin to assume a cellular structure.

foam-in-place. Refers to the deposition of foams when the foaming machine must be brought to the work that is "in place," as opposed to bringing the work to the foaming machine. Also, foam mixed in a container and poured into a mold, where it rises to fill the cavity.

force. The male half of the mold that enters the cavity, exerting pressure on the resin and causing it to flow. Also called punch.

FP fiber. Polycrystalline alumina fiber (Al_2O_3). A ceramic fiber useful for high-temperature (1370 to 1650 °C, or 2500 to 3000 °F) composites.

fracture. The separation of a body. Defined both as rupture of the surface without complete separation of laminate and as complete separation of a body because of external or internal forces.

fracture stress. The true, normal stress on the minimum cross-sectional area at the beginning of fracture.

fracture toughness. A measure of the damage tolerance of a material containing initial flaws or cracks. Used in aircraft structural design and analysis.

used as base materials for the manufacture of certain high-modulus carbon fibers and as matrix precursors for carbon-carbon composites.

plain weave. A weaving pattern in which the warp and fill fibers alternate; that is, the repeat pattern is warp/fill/warp/fill, and so on. Both faces of a plain weave are identical. Properties are significantly reduced relative to a weaving pattern with fewer crossovers.

planar. Lying essentially in a single plane.

planar helix winding. A winding in which the filament path on each dome lies on a plane that intersects the dome, while a helical path over the cylindrical section is connected to the dome paths.

planar winding. A winding in which the filament path lies on a plane that intersects the winding surface. See also *polar winding*.

plastic. A material that contains as an essential ingredient an organic polymer of large molecular weight, hardeners, fillers, reinforcements, and so forth; is solid in its finished state; and, at some stage in its manufacture or its processing into finished articles, can be shaped by flow. Made of plastic. A plastic may be either thermoplastic or thermoset.

plastic deformation. Change in dimensions of an object under load that is not recovered when the load is removed, as opposed to elastic deformation.

plastic flow. Deformation under the action of a sustained hot or cold force. Flow of semisolids in the molding of plastics.

plasticizer. A material incorporated in a plastic to increase its workability and flexibility or distensibility. Normally used in thermoplastics. A lower molecular weight material added to an epoxy to reduce stiffness and brittleness, thereby resulting in a lower glass transition temperature for the polymer.

plastic memory. The tendency of a thermoplastic material that has been stretched while hot to return to its unstretched shape upon being reheated.

platens. The mounting plates of a press, to which the entire mold assembly is bolted.

plied yarn. Yarn made by collecting two or more single yarns. Normally, the yarns are twisted together, though sometimes they are collected without twist.

ply. In general, fabrics or felts consisting of one or more layers (laminates, and so forth). The layers that make up a stack. Yarn resulting from twisting operations (three-ply yarn, and so forth). A single layer of prepreg. A single pass in filament winding (two plies forming one layer).

PMR polyimides. A novel class of high temperature resistant polymers. PMR represents *in situ* polymerization of monomer reactants.

Poisson's ratio. The ratio of the change in lateral width per unit width to change in axial length per unit length caused by the axial stretching or stressing of a material. The ratio of transverse strain to the corresponding axial strain below the proportional limit.

polar winding. A winding in which the filament path passes tangent to the polar opening at one end of the chamber and tangent to the opposite side of the polar opening at the other end. A one-circuit pattern is inherent in the system.

polyacrylonitrile (PAN). Used as a base material or precursor in the manufacture of certain carbon fibers.

polyamide. A thermoplastic polymer in which the structural units are linked by amide or thio-amide groupings (repeated nitrogen and hydrogen groupings). Many polyamides are fiber forming.

polyamideimide. A polymer containing both amide (nylon) and imide (as in polyimide) groups; properties combine the benefits and disadvantages of both.

polyamide plastic. See *nylon plastics*.

polyarylsulfone (PAS). A high temperature resistant thermoplastic (T_g = 275 °C, or 527 °F). The term is also occasionally used to describe the family of resins which includes polysulfone and polyethersulfone.

polybenzimidazole (PBI). A condensation polymer of diphenyl isophthalate and 3,3′-diaminobenzidine. Extremely high-temperature resistant. Available as adhesive and fiber.

polycarbonate resin. A thermoplastic polymer derived from the direct reaction between aromatic and aliphatic dihydroxy compounds with phosgene or by the ester exchange reaction with appropriate phosgene-derived precursors. Highest impact resistance of any transparent plastic.

polycondensation. See *condensation polymerization*.

polyesters, thermoplastic. See *thermoplastic polyesters*.

polyesters, thermosetting. See *thermosetting polyesters*.

polyether etherketone (PEEK). A linear aromatic crystalline thermoplastic. A composite with a PEEK matrix may have a continuous-use temperature as high as 250 °C (480 °F).

polyetherimide. An amorphous polymer with good thermal properties for a thermoplastic. Reported T_g of 215 °C (419 °F) and continuous-use temperature of about 170 °C (338 °F).

polyimide (PI). A polymer produced by reacting an aromatic dianhydride with an aromatic diamine. It is a highly heat-resistant resin ≥ 315 °C (600 °F). Similar to a polyamide, differing only in the number of hydrogen molecules contained in the groupings. Suitable for use as a binder or adhesive. May be either thermoplastic or thermoset.

polymer. A high molecular weight organic compound, natural or synthetic, whose structure can be represented by a repeated small unit, the mer, for example, polyethylene, rubber, and cellulose. Synthetic polymers are formed by addition or condensation polymerization of monomers. Some polymers are elastomers, some are plastics, and some are fibers. When two or more dissimilar monomers are involved, the product is called a copolymer. The chain lengths of commercial thermoplastics vary from near a thousand to over one hundred thousand repeating units. Thermosetting polymers approach infinity after curing, but their resin precursors, often called prepolymers, may be relatively short—6 to 100 repeating units—before curing. The lengths of polymer chains, usually measured by molecular weight, have very significant effects on the performance properties of plastics and profound effects on processibility.

polymerization. A chemical reaction in which the molecules of a monomer are linked together to form large molecules whose molecular weight is a multiple of that of the original substance. When two or more monomers are involved, the process is called copolymerization.

polymer matrix. The resin portion of a reinforced or filled plastic.

polymethyl methacrylate. A thermoplastic polymer synthesized from methyl methacrylate. It is a transparent solid with exceptional optical properties; available in the form of sheets, granules, solutions, and emulsions. Used as facing material in certain composite constructions. See also *acrylic plastic*.

polyphenylene sulfide (PPS). A high-temperature thermoplastic useful primarily as a molding compound. Optimum properties depend on slightly cross-linking the resin. Known for chemical resistance.

polypropylene. A tough, lightweight, thermoplastic made by the polymerization of high-purity propylene gas in the presence of an organometallic catalyst at relatively low pressures and temperatures.

polysulfide. A synthetic polymer containing sulfur and carbon linkages, produced from organic dihalides and sodium polysulfide. Material is elastomeric in nature, resistant to light, oil, and solvents, and impermeable to gases.

polysulfone. A high temperature resistant thermoplastic polymer with the sulfone linkage, with a T_g of 190 °C (375 °F).

polyurethane. A thermosetting resin prepared by the reaction of diisocyanates with polyols, polyamides, alkyd polymers, and polyether polymers. See also *isocyanate plastics* and *urethane plastics*.

heat build-up. The rise in temperature in a part resulting from the dissipation of applied strain energy as heat or from applied mold cure heat. See also *hysteresis*.

heat cleaned. A condition in which glass or other fibers are exposed to elevated temperatures to remove preliminary sizings or binders not compatible with the resin system to be applied.

heat distortion point. The temperature at which a standard test bar deflects a specified amount under a stated load. Now called deflection temperature.

heat resistance. The property or ability of plastics and elastomers to resist the deteriorating effects of elevated temperatures.

heat sealing. A method of joining plastic films by simultaneous application of heat and pressure to areas in contact.

heat-sealing adhesive. A thermoplastic film adhesive that is melted between the adherend surfaces by heat application to one or both of the adjacent adherend surfaces.

heat sink. A contrivance for the absorption or transfer of heat away from a critical element or part. Bulk graphite is often used as a heat sink.

heat treating. Term used to cover annealing, hardening, tempering, and so forth.

helical winding. In filament wound items, a winding in which a filament band advances along a helical path, not necessarily at a constant angle except in the case of a cylinder.

heterogeneous. Descriptive term for a material consisting of dissimilar constituents separately identifiable. A medium consisting of regions of unlike properties separated by internal boundaries. Note that not all nonhomogeneous materials are necessarily heterogeneous.

hexa. Shortened form of hexamethylenetetramine, a source of reactive methylene for curing novolacs.

high-frequency heating. The heating of materials by dielectric loss in a high-frequency electrostatic field. The material is exposed between electrodes and is heated quickly and uniformly by absorption of energy from the electrical field.

high-pressure laminates. Laminates molded and cured at pressures not lower than 6.9 MPa (1.0 ksi), and more commonly in the range of 8.3 to 13.8 MPa (1.2 to 2.0 ksi).

high-pressure spot. See *resin-starved area*.

HIP. See *hot isostatic pressing*.

homogeneous. Descriptive term for a material of uniform composition throughout. A medium that has no internal physical boundaries. A material whose properties are constant at every point, that is, constant with respect to spatial coordinates (but not necessarily with respect to directional coordinates).

honeycomb. Manufactured product of resin-impregnated sheet material (paper, glass fabric, and so on) or metal foil, formed into hexagonal-shaped cells. Used as a core material in sandwich constructions. See also *sandwich constructions*.

hoop stress. The circumferential stress in a material of cylindrical form subjected to internal or external pressure.

hot isostatic pressing. A process for fabricating certain metal matrix composites. A preform is consolidated under fluid pressure (usually an inert gas) at high temperature and pressure in a pressure vessel.

hot-melt adhesive. An adhesive that is applied in a molten state and forms a bond after cooling to a solid state. A bonding agent that achieves a solid state and resultant strength by cooling, as contrasted with other adhesives, which achieve the solid state through evaporation of solvents or chemical cure. A thermoplastic resin that functions as an adhesive when melted between substrates and cooled.

hot-setting adhesive. An adhesive that requires a temperature at or above 100 °C (212 °F) to set.

hot working. Any form of mechanical deformation processing carried out on a metal or alloy above its recrystallization temperature but below its melting point.

hybrid. A composite laminate consisting of laminae of two or more composite material systems. A combination of two or more different fibers, such as carbon and glass or carbon and aramid, into a structure. Tapes, fabrics, and other forms may be combined; usually only the fibers differ. See also *interply hybrid* and *intraply hybrid*.

hydraulic press. A press in which the molding force is created by the pressure exerted by a fluid.

hydromechanical press. A press in which the molding forces are created partly by a mechanical system and partly by an hydraulic system.

hydrophilic. Capable of absorbing water. Easily wetted by water.

hydrophobic. Capable of repelling water. Poorly wetted by water.

hygroscopic. Capable of adsorbing and retaining atmospheric moisture.

hygrothermal effect. Change in properties due to moisture absorption and temperature change.

hysteresis. The energy absorbed in a complete cycle of loading and unloading. This energy is converted from mechanical to frictional energy (heat).

I

ignition loss. The difference in weight before and after burning. As with glass, the burning off of the binder or size.

impact strength. The ability of a material to withstand shock loading. The work done in fracturing a test specimen in a specified manner under shock loading.

impact test. Measure of the energy necessary to fracture a standard notched bar by an impulse load. See also *Izod impact test*, *reverse impact test*, and *Charpy impact test*.

impregnate. In reinforced plastics, to saturate the reinforcement with a resin.

impregnated fabric. A fabric impregnated with a synthetic resin. See also *prepreg*.

inclusion. A physical and mechanical discontinuity occurring within a material or part, usually consisting of solid, encapsulated foreign material. Inclusions are often capable of transmitting some structural stresses and energy fields, but in a noticeably different degree from the parent material. See also *voids*.

inert filler. A material added to a plastic to alter the end-item properties through physical rather than chemical means.

infrared. Part of the electromagnetic spectrum between the visible light range and the radar range. Radiant heat is in this range, and infrared heaters are frequently used in the thermoforming and curing of plastics and composites. Infrared analysis is used for identification of polymer constituents.

inhibitor. A substance that retards a chemical reaction. Also used in certain types of monomers and resins to prolong storage life.

initial modulus. The slope of the initial straight portion of a stress-strain or load-elongation curve. See also *Young's modulus*.

initial strain. The strain produced in a specimen by given loading conditions before creep occurs.

initial (instantaneous) stress. The stress produced by force in a specimen before stress relaxation occurs.

initiator. Peroxides used as sources of free radicals. They are used in free-radical polymerizations, for curing thermosetting resins, as cross-linking agents for elastomers and polyethylene, and for polymer modification.

injection molding. Method of forming a plastic to the desired shape by forcing the heat-softened plastic into a relatively cool cavity under pressure.

inorganic pigments. Natural or synthetic metallic oxides, sulfides, and other salts that

modulus, secant. See *secant modulus*.

modulus, tangent. See *tangent modulus*.

Mohs hardness. A measure of the scratch resistance of a material. The higher the number, the greater the scratch resistance (No. 10 being termed diamond).

moisture absorption. The pickup of water vapor from air by a material. It relates only to vapor withdrawn from the air by a material and must be distinguished from water absorption, which is the gain in weight due to the take-up of water by immersion.

moisture content. The amount of moisture in a material determined under prescribed conditions and expressed as a percentage of the mass of the moist specimen, that is, the mass of the dry substance plus the moisture present.

moisture equilibrium. The condition reached by a sample when it no longer takes up moisture from, or gives up moisture to, the surrounding environment.

moisture vapor transmission. A rate at which water vapor passes through a material at a specified temperature and relative humidity (g/mil/24 h/100 $in.^2$).

mold. The cavity or matrix into or on which the plastic composition is placed and from which it takes form. To shape plastic parts or finished articles by heat and pressure. The assembly of all the parts that function collectively in the molding process.

molded edge. An edge that is not physically altered after molding for use in final form, and particularly one that does not have fiber ends along its length.

molded net. Description of a molded part that requires no additional processing to meet dimensional requirements.

molding. The forming of a polymer or composite into a solid mass of prescribed shape and size by the application of pressure and heat for given times. Sometimes used to denote the finished part.

molding cycle. The period of time required for the complete sequence of operations on a molding press to produce one set of moldings. The operations necessary to produce a set of moldings without reference to the total time taken.

molding powder or compound. Plastic material in varying stages of pellets or granulation, and consisting of resin, filler, pigments, reinforcements, plasticizers, and other ingredients, ready for use in the molding operation.

molding pressure. The pressure applied to the ram of an injection machine or compression or transfer press to force the softened plastic to fill the mold cavities completely.

mold-release agent. A lubricant, liquid, or powder (often silicone oils and waxes), used to prevent sticking of molded articles in the cavity.

mold shrinkage. The immediate shrinkage that a molded part undergoes when it is removed from a mold and cooled to room temperature. The difference in dimensions, expressed in inches per inch, between a molding and the mold cavity in which it was molded (at normal-temperature measurement). The incremental difference between the dimensions of the molding and the mold from which it was made, expressed as a percentage of the mold dimensions.

mold surface. The side of a laminate that faced the mold (tool) during cure in an autoclave or hydroclave.

molecular weight. The sum of the atomic weights of all the atoms in a molecule. A measure of the chain length for the molecules that make up the polymer.

monofilament. A single fiber or filament of indefinite length, strong enough to function as a yarn in commercial textile operations.

monolayer. The basic laminate unit from which cross-plied or other laminate types are constructed. Also, a "single" layer of atoms or molecules adsorbed on or applied to a surface.

monomer. A single molecule that can react with like or unlike molecules to form a polymer. The smallest repeating structure of a polymer (mer). For additional polymers, this represents the original unpolymerized compound.

morphology. The overall form of a polymer structure, that is, crystallinity, branching, molecular weight, and so on.

multicircuit winding. In filament winding, a winding that requires more than one circuit before the band repeats by laying adjacent to the first band.

multifilament yarn. A large number (500 to 2000) of fine, continuous filaments (often 5 to 100 individual filaments) usually with some twist in the yarn to facilitate handling.

MVT. See *moisture vapor transmission*.

N

NDE. See *nondestructive evaluation*.

NDI. See *nondestructive inspection*.

NDT. See *nondestructive testing*.

neat resin. Resin to which nothing (additives, reinforcements, and so on) has been added.

necking. The localized reduction in cross section that may occur in a material under tensile stress.

needled mat. A mat formed of strands cut to a short length, then felted together in a needle loom, with or without a carrier.

nesting. In reinforced plastics, the placing of plies of fabric so that the yarns of one ply lie in the valleys between the yarns of the adjacent ply (nested cloth).

netting analysis. The analysis of filament-wound structures that assumes the stresses induced in the structure are carried entirely by the filaments, and the strength of the resin is neglected; and assumes also that the filaments possess no bending or shearing stiffness, and carry only the axial tensile loads.

node. The connected portion of adjacent ribbons of honeycomb.

NOL ring. A parallel filament- or tape-wound hoop test specimen developed by the Naval Ordnance Laboratory (NOL), (now the Naval Surface Weapons Laboratory), for measuring various mechanical strength properties of the material, such as tension and compression, by testing the entire ring or segments of it. Also known as a parallel fiber reinforced ring.

nominal stress. The stress at a point calculated on the net cross section without taking into consideration the effect on stress of geometric discontinuities, such as holes, grooves, fillets, and so forth. The calculation is made by simple elastic theory.

nominal value. A value assigned for the purpose of a convenient designation. A nominal value exists in name only. It is often an average number with a tolerance so as to fit together with adjacent parts.

nondestructive evaluation (NDE). Broadly considered synonymous with nondestructive inspection (NDI). More specifically, the analysis of NDI findings to determine whether the material will be acceptable for its function.

nondestructive inspection (NDI). A process or procedure, such as ultrasonic or radiographic inspection, for determining the quality or characteristics of a material, part, or assembly, without permanently altering the subject or its properties. Used to find internal anomalies in a structure without degrading its properties.

nondestructive testing (NDT). Broadly considered synonymous with nondestructive inspection (NDI).

nonhygroscopic. Lacking the property of absorbing and retaining an appreciable quantity of moisture (water vapor) from the air.

nonwoven fabric. A planar textile structure produced by loosely compressing together fibers, yarns, rovings, and so forth, with or without a scrim cloth carrier. Accomplished by mechanical, chemical, thermal, or solvent means and combinations thereof.

normal stress. The stress component that is perpendicular to the plane on which the forces act.

reinforcing material in position in the mold. The resin-impregnated reinforcement. A description of the component materials, geometry, and so forth, of a laminate.

L-direction. The ribbon direction, that is, the direction of the continuous sheets of honeycomb.

level winding. See *circumferential winding*.

linear expansion. The increase of a given dimension, measured by the expansion or contraction of a specimen or component subject to a thermal gradient or changing temperature. See also *coefficient of thermal expansion*.

liner. In a filament-wound pressure vessel, the continuous, usually flexible coating on the inside surface of the vessel, used to protect the laminate from chemical attack or to prevent leakage under stress.

liquid crystal polymer. A newer thermoplastic polymer that is melt processable and develops high orientation in molding, with resultant tensile strength and high-temperature capability that is notably improved. First commercial availability was as an aromatic polyester. With or without fiber reinforcement.

liquid metal infiltration. Process for immersion of metal fibers in a molten metal bath to achieve a metal matrix composite; for example, graphite fibers in molten aluminum.

liquid shim. Material used to position components in an assembly where dimensional alignment is critical. For example, epoxy adhesive is introduced into gaps after the assembly is placed in the desired configuration.

load-deflection curve. A curve in which the increasing tension, compression, or flexural loads are plotted on the ordinate axis and the deflections caused by those loads are plotted on the abscissa axis.

longos. Low angle helical or longitudinal windings.

loop tenacity. The tenacity or strength value obtained by pulling two loops, as two links in a chain, against each other in order to demonstrate the susceptibility that a fibrous material has for cutting or crushing itself; loop strength.

loss factor. The product of the dissipation factor and the dielectric constant of a dielectric material.

loss modulus. A damping term describing the dissipation of energy into heat when a material is deformed.

loss on ignition. Weight loss, usually expressed as percent of total, after burning off an organic sizing from glass fibers, or an organic resin from a glass fiber laminate.

loss tangent. See *electrical dissipation factor*.

lot. A specific amount of material produced at one time using the same process and the same conditions of manufacture, and offered for sale as a unit quantity.

low-pressure laminates. In general, laminates molded and cured in the range of pressures from 2760 kPa (400 psi) down to and including pressure obtained by the mere contact of the plies.

lubricant. A material added to most sizings to improve the handling and processing properties of textile strands, especially during weaving.

M

macerate. To chop or shred fabric for use as a filler for a molding resin.

macro. In relation to composites, denotes the gross properties of a composite as a structural element but does not consider the individual properties or identity of the constituents.

mandrel. The core tool around which resin-impregnated paper, fabric, or fiber is wound to form pipes, tubes, or structural shell shapes.

mat. A fibrous material for reinforced plastic consisting of randomly oriented chopped filaments, short fibers (with or without a carrier fabric), or swirled filaments loosely held together with a binder. Available in blankets of various widths, weights, and lengths. Also, a sheet formed by filament winding a single-hoop ply of fiber on a mandrel, cutting across its width and laying out a flat sheet.

matched metal molding. A reinforced plastics manufacturing process in which matching male and female metal molds are used (similar to compression molding) to form the part, with time, pressure, and heat.

matrix. The essentially homogeneous resin or polymer material in which the fiber system of a composite is imbedded. Both thermoplastic and thermoset resins may be used, as well as metals, ceramics, and glasses.

mechanical adhesion. Adhesion between surfaces in which the adhesive holds the parts together by interlocking action.

mechanical properties. The properties of a material, such as compressive and tensile strengths, and modulus, that are associated with elastic and inelastic reaction when force is applied. The individual relationship between stress and strain.

melt. A charge of molten metal. See also *liquid metal infiltration*.

mer. The repeating structural unit of any polymer.

mesophase. An intermediate phase in the formation of carbon from a pitch precursor. This is a liquid crystal phase in the form of microspheres, which upon prolonged heating above 400 °C (750 °F) coalesce, solidify, and form regions of extended order. Heating to above 2000 °C (3630 °F) leads to the formation of graphite structure.

metallic fiber. Manufactured fiber composed of metal, plastic-coated metal, metal-coated plastic, or a core completely covered by metal.

M-glass. A high beryllia (BeO_2) content glass designed especially for high modulus of elasticity.

micro. In relation to composites, denotes the properties of the constituents, that is, matrix, reinforcement, and interface only, and their effects on the composite properties.

microcracking. Cracks formed in composites when thermal stresses locally exceed the strength of the matrix. Since most microcracks do not penetrate the reinforcing fibers, microcracks in a cross-plied tape laminate or in a laminate made from cloth prepreg are usually limited to the thickness of a single ply.

microstructure. A structure with heterogeneities that can be seen through a microscope.

mil. The unit used in measuring the diameter of glass fiber strands, wire, and so forth (1 mil = 0.001 in.).

milled fiber. Continuous glass strands hammer milled into very short glass fibers. Useful as inexpensive filler or anticrazing reinforcing fillers for adhesives.

modulus, initial. See *initial modulus*.

modulus of elasticity. The ratio of the stress or load applied to the strain or deformation produced in a material that is elastically deformed. If a tensile strength of 13.8 MPa (2.0 ksi) results in an elongation of 1%, the modulus of elasticity is 13.8 MPa (2.0 ksi) divided by 0.01, or 1380 MPa (200 ksi). Also called Young's modulus. See also *offset modulus* and *secant modulus*.

modulus, offset. See *offset modulus*.

modulus of resilience. The energy that can be absorbed per unit volume without creating a permanent distortion. Calculated by integrating the stress-strain curve from zero to the elastic limit and dividing by the original volume of the specimen.

modulus of rigidity. The ratio of stress to strain within the elastic region for shear or torsional stress. Also called shear modulus or torsional modulus.

modulus of rupture, in bending. The maximum tensile or compressive stress value (whichever causes failure) in the extreme fiber of a beam loaded to failure in bending.

modulus of rupture, in torsion. The maximum shear stress in the extreme fiber of a member of circular cross section loaded to failure in torsion.

impart heat and light stability, weathering resistance, color, and migration resistance to plastics.

insert. An integral part of a plastic molding consisting of metal or other material that may be molded or pressed into position after the molding is completed.

insulation resistance. The electrical resistance between two conductors or systems of conductors separated only by insulating material. The ratio of the applied voltage to the total current between two electrodes in contact with a specified insulator. The electrical resistance of an insulating material to a direct voltage.

insulator. A material of such low electrical conductivity that the flow of current through it can usually be neglected. Similarly, a material of low thermal conductivity, such as that used to insulate structural shells.

integral composite structure. Composite structure in which several structural elements, which would conventionally be assembled together by bonding or mechanical fasteners after separate fabrication, are instead laid up and cured as a single, complex, continuous structure, for example, spars, ribs, and one stiffened cover of a wing box fabricated as a single integral part. The term is sometimes applied more loosely to any composite structure not assembled by mechanical fasteners. All or some parts of the assembly may be co-cured.

integrally heated. A term referring to tooling that is self-heating, through use of electrical heaters such as cal rods. Most hydroclave tooling is integrally heated. Some autoclave tooling is integrally heated to compensate for thick sections, to provide high heat-up rates, or to permit processing at a higher temperature than is otherwise possible with the autoclave.

integral skin foam. Urethane foam with a cellular core structure and a relatively nonporous skin.

interface. The boundary or surface between two different, physically distinguishable media. On fibers, the contact area between fibers and sizing or finish. In a laminate, the contact area between the reinforcement and the laminating resin.

interference fits. A joint or mating of two parts in which the male part has an external dimension larger than the internal dimension of the mating female part. Distension of the female by the male creates a stress, which supplies the bonding force for the joint.

interlaminar. Descriptive term pertaining to an object (for example, voids), event (for example, fracture), or potential field (for example, shear stress) referenced as existing or occurring between two or more adjacent laminae.

interlaminar shear. Shearing force tending to produce a relative displacement between two laminae in a laminate along the plane of their interface.

intermediate temperature setting adhesive. An adhesive that sets in the temperature range from 30 to 100 °C (87 to 211 °F).

interphase. The boundary region between a bulk resin or polymer and an adherend in which the polymer has a high degree of orientation to the adherend on a molecular basis. It plays a major role in the load transfer process between the bulk of the adhesive and the adherend or the fiber and the laminate matrix resin.

interply hybrid. A composite in which adjacent laminae are composed of different materials.

intralaminar. Descriptive term pertaining to an object (for example, voids), event (for example, fracture), or potential field (for example, temperature gradient) existing entirely within a single lamina without reference to any adjacent laminae.

intraply hybrid. A composite in which different materials are used within a specific layer or band.

irradiation. As applied to plastics, the bombardment with a variety of subatomic particles, usually alpha-, beta-, or gamma-rays. Used to initiate polymerization and copolymerization of plastics and in some cases to bring about changes in the physical properties of a plastic.

irreversible. Not capable of redissolving or remelting. Chemical reactions that proceed in a single direction and are not capable of reversal (as applied to thermosetting resins).

isocyanate plastics. Plastics based on resins made by the condensation of organic isocyanates with other compounds. Generally reacted with polyols on a polyester or polyether backbone molecule, with the reactants being joined through the formation of the urethane linkage. See also *polyurethane* and *urethane plastics*.

isostatic pressing. Pressing powder under a gas or liquid so that pressure is transmitted equally in all directions, for example, in sintering.

isotropic. Having uniform properties in all directions. The measured properties of an isotropic material are independent of the axis of testing.

Izod impact test. A test for shock loading in which a notched specimen bar is held at one end and broken by striking, and the energy absorbed is measured.

J

joint, adhesive. See *adhesive joint*.

joint, butt. See *butt joint*.

joint, edge. See *edge joint*.

joint, lap. See *lap joint*.

joint, scarf. See *scarf joint*.

K

kerf. The width of a cut made by a saw blade, torch, water jet, laser beam, and so forth.

Kevlar. An organic polymer composed of aromatic polyamides having a para-type orientation (parallel chain extending bonds from each aromatic nucleus).

knitted fabrics. Fabrics produced by interlooping chains of yarn.

***K* factor.** The coefficient of thermal conductivity. The amount of heat that passes through a unit cube of material in a given time when the difference in temperature of two opposite faces is 1°.

knuckle area. The area of transition between sections of different geometry in a filament-wound part, for example, where the skirt joins the cylinder of the pressure vessel. Also called Y-joint.

L

lamina. A single ply or layer in a laminate made up of a series of layers (organic composite). A flat or curved surface containing unidirectional fibers or woven fibers embedded in a matrix (metal matrix composite).

laminae. Plural of lamina.

laminate. To unite laminae with a bonding material, usually with pressure and heat (normally used with reference to flat sheets, but also rods and tubes). A product made by such bonding. See also *bidirectional laminate* and *unidirectional laminate*.

laminate coordinates. A reference coordinate system (used to describe the properties of a laminate), generally in the direction of principal axes, when they exist.

laminate orientation. The configuration of a cross-plied composite laminate with regard to the angles of cross-plying, the number of laminae at each angle, and the exact sequence of the lamina lay-up.

laminate ply. One fabric-resin or fiber-resin layer of a product that is bonded to adjacent layers in the curing process.

lap. In filament winding, the amount of overlay between successive windings, usually intended to minimize gapping. In bonding, the distance one adherend covers another adherend.

lap joint. A joint made by placing one adherend partly over another and bonding the overlapped portions.

lattice pattern. A pattern of filament winding with a fixed arrangement of open voids.

lay-up. The reinforcing material placed in position in the mold. The process of placing the

notched specimen. A test specimen that has been deliberately cut or notched, usually in a V-shape, to induce and locate point of failure.

notch factor. Ratio of the resilience determined on a plain specimen to the resilience determined on a notched specimen.

notch sensitivity. The extent to which the sensitivity of a material to fracture is increased by the presence of a surface nonhomogeneity, such as a notch, a sudden change in section, a crack, or a scratch. Low notch sensitivity is usually associated with ductile materials, and high notch sensitivity is usually associated with brittle materials.

novolac. A linear thermoplastic B-staged phenolic resin, which, in the presence of methylene or other cross-linking groups, reacts to form a thermoset phenolic.

nylon. The generic name for all synthetic polyamides.

nylon plastics. Plastics based on a resin composed principally of a long-chain synthetic polymeric amide that has recurring amide groups as an integral part of the main polymer chain. Numerical designations (nylon 6, nylon 66, and so on) refer to the monomeric amides of which they are made. Characterized by great toughness and elasticity.

O

offset modulus. The ratio of the offset yield stress to the extension at the offset point.

offset yield strength. The stress at which the strain exceeds by a specific amount (the offset) an extension of the initial approximately linear proportional portion of the stress-strain curve. It is expressed in force per unit area.

olefin. A group of unsaturated hydrocarbons of the general formula C_nH_{2n} named after the corresponding paraffins by the addition of "ene" or "ylene" to the root, for example, ethylene, propylene, and pentene.

open-cell foam. Foamed or cellular material with cells that are generally interconnected. Closed cell refers to cells that are not interconnected.

orange peel. An uneven surface somewhat resembling that of an orange peel; said of injection moldings that have unintentionally ragged surfaces.

organic. Matter originating in plant or animal life or composed of chemicals of hydrocarbon origin, either natural or synthetic.

orientation. The alignment of the crystalline structure in polymeric materials in order to produce a highly aligned structure. Orientation can be accomplished by cold drawing or stretching in fabrication.

oriented materials. Materials, particularly amorphous polymers and composites, whose molecules and/or macroconstituents are aligned in a specific way. Oriented materials are anisotropic. Orientation can generally be divided into two classes, uniaxial and biaxial.

orthotropic. Having three mutually perpendicular planes of elastic symmetry.

out time. The time a prepreg is exposed to ambient temperature, namely, the total amount of time the prepreg is out of the freezer. The primary effects of out time are to decrease the drape and tack of the prepreg while also allowing it to absorb moisture from the air.

ovaloid. A surface of revolution symmetrical about the polar axis that forms the end closure for a filament-wound cylinder.

oven dry. The condition of a material that has been heated under prescribed conditions of temperature and humidity until there is no further significant change in its mass.

overlay sheet. A nonwoven fibrous mat (of glass, synthetic fiber, and so forth) used as the top layer in a cloth or mat lay-up, to provide a smoother finish, minimize the appearance of the fibrous pattern, or permit machining or grinding to a precise dimension. Also called surfacing mat.

oxidation. In carbon/graphite fiber processing, the step of reacting the precursor polymer (rayon, PAN, or pitch) with oxygen, resulting in stabilization of the structure for the hot stretching operation. In general usage, oxidation refers to any chemical reaction in which electrons are transferred.

P

package. Yarn, roving, and so forth in the form of units capable of being unwound and suitable for handling, storing, shipping, and use.

PAN. See *polyacrylonitrile*.

parallel laminate. A laminate of woven fabric in which the plies are aligned in the same position as originally aligned in the fabric roll. A series of flat or curved cloth-resin layers stacked uniformly on top of each other.

particulate composite. Material consisting of one or more constituents suspended in a matrix of another material. These particles are either metallic or nonmetallic.

parting agent. See *mold release agent*.

parting line. A mark on a molded piece where the sections of a mold have met in closing.

PAS. See *polyarylsulfone*.

PBI. See *polybenzimidazole*.

PEEK. See *polyether etherketone*.

peel ply. A layer of open-weave material, usually fiberglass or heat-set nylon, applied directly to the surface of a prepreg lay-up. The peel ply is removed from the cured laminate immediately before bonding operations, leaving a clean, resin-rich surface that needs no further preparation for bonding, other than application of a primer where one is required.

peel strength. Adhesive bond strength, as in pounds per inch of width, obtained by a stress applied in a peeling mode.

permanence. The property of a plastic that describes its resistance to appreciable changes in characteristics with time and environment.

permanent set. The deformation remaining after a specimen has been stressed a prescribed amount in tension, compression, or shear for a definite time period and released for a definite time period. For creep tests, the residual unrecoverable deformation after the load causing the creep has been removed for a substantial and definite period of time. Also, the increase in length, expressed as a percentage of the original length, by which an elastic material fails to return to original length after being stressed for a standard period of time.

permeability. The passage or diffusion (or rate of passage) of a gas, vapor, liquid, or solid through a barrier without physically or chemically affecting it.

pH. The measure of the acidity or alkalinity of a substance, neutrality being at pH 7. Acid solutions are less than 7, alkaline solutions are more than 7.

phenolic (phenolic resin). A thermosetting resin produced by the condensation of an aromatic alcohol with an aldehyde, particularly of phenol with formaldehyde. Used in high-temperature applications with various fillers and reinforcements.

phenylsilane resins. Thermosetting copolymers of silicone and phenolic resins. Furnished in solution form.

physical catalyst. Radiant energy capable of promoting or modifying a chemical reaction.

PI. See *polyimide*.

PIC. See *pressure-impregnation-carbonization*.

pick count. The number of filling yarns per inch of woven fabric.

pin holes. Small cavities that penetrate the surface of a cured part.

pit. A small, regular or irregular crater in the surface of a plastic, usually of a width approximately the same order of magnitude as its depth.

pitch. A high molecular weight material left as a residue from the destructive distillation of coal and petroleum products. Pitches are

free-radical polymerization. A type of polymerization in which the propagating species is a long-chain free radical initiated by the introduction of free radicals from thermal or photochemical decomposition.

free wall. The portion of a honeycomb cell wall that is not connected to another cell.

friction, coefficient of. See *coefficient of friction*.

FRP. See *fiber-reinforced plastic*.

fungus resistance. The resistance of a material to attack by fungi in conditions promoting their growth.

fuzz. Accumulation of short broken filaments after passing glass strands, yarns, or rovings over a contact point. Often weighted and used as an inverse measure of abrasion resistance.

G

gage length. Length over which deformation is measured, for a tensile or compressive test specimen. The deformation over the gage length divided by the gage length determines the strain.

gap. In filament winding, the space between successive windings, which windings are usually intended to lay next to each other. Separations between fibers within a filament winding band. The distance between adjacent plies in a lay-up of unidirectional tape materials.

gap-filling adhesive. An adhesive subject to low shrinkage in setting, used as sealant.

gel. The initial jellylike solid phase that develops during the formation of a resin from a liquid. A semisolid system consisting of a network of solid aggregates in which liquid is held.

gelation. The point in a resin cure when the resin viscosity has increased to a point such that it barely moves when probed with a sharp instrument.

gelation time. That interval of time, in connection with the use of synthetic thermosetting resins, extending from the introduction of a catalyst into a liquid adhesive system until the start of gel formation. Also, the time under application of load for a resin to reach a solid state.

gel coat. A quick setting resin applied to the surface of a mold and gelled before lay-up. The gel coat becomes an integral part of the finished laminate, and is usually used to improve surface appearance and bonding.

gel permeation chromatography (GPC). A form of liquid chromatography in which the polymer molecules are separated by their ability or inability to penetrate the material in the separation column.

gel point. The stage at which a liquid begins to may be conveniently observed from the inflection point on a viscosity time plot.

geodesic. The shortest distance between two points on a surface.

geodesic isotensoid. Constant stress level in any given filament at all points in its path.

geodesic-isotensoid contour. In filament wound reinforced plastic pressure vessels, a dome contour in which the filaments are placed on geodesic paths so that the filaments will exhibit uniform tensions throughout their length under pressure loading.

geodesic ovaloid. A contour for end domes, the fibers forming a geodesic line: the shortest distance between two points on a surface of revolution. The forces exerted by the filaments are proportioned to meet hoop and meridional stresses at any point.

glass. An inorganic product of fusion that has cooled to a rigid condition without crystallizing. Glass is typically hard and relatively brittle, and has a conchoidal fracture.

glass cloth. Conventionally woven glass fiber material. See also *scrim*.

glass fiber. A fiber spun from an inorganic product of fusion that has cooled to a rigid condition without crystallizing.

glass filament. A form of glass that has been drawn to a small diameter and extreme length. Most filaments are less than 0.15 mm (0.005 in.) in diameter.

glass filament bushing. The unit through which molten glass is drawn in making glass filaments.

glass finish. A material applied to the surface of a glass reinforcement to improve the bond between the glass and the plastic resin matrix.

glass flake. Thin, irregularly shaped flakes of glass, typically made by shattering a thin-walled tube of glass.

glass former. An oxide that forms a glass easily. Also, one which contributes to the network of silica glass when added to it.

glass, percent by volume. The product of the specific gravity of a laminate and the percent glass by weight, divided by the specific gravity of the glass.

glass stress. In a filament wound part, usually a pressure vessel, the stress calculated using the load and the cross-sectional area of the reinforcement only.

glass transition. The reversible change in an amorphous polymer or in amorphous regions of a partially crystalline polymer from, or to, a viscous or rubbery condition to, or from, a hard and relatively brittle one.

glass transition temperature (T_g). The approximate midpoint of the temperature range over which the glass transition takes place; glass and silica fiber exhibit a phase change at approximately 955 °C (1750 °F) and carbon/graphite fibers at 2205 to 2760 °C (4000 to 5000 °F). The temperature at which increased molecular mobility results in significant changes in the properties of a cured resin system. Also, the inflection point on a plot of modulus versus temperature. The measured value of T_g depends to some extent on the method of test.

graphite. The crystalline allotropic form of carbon.

graphite fiber. A fiber made from a precursor by oxidation, carbonization, and graphitization process (which provides a graphitic structure). See also *carbon fiber*.

graphitization. The process of pyrolyzation in an inert atmosphere at temperatures in excess of 1925 °C (3500 °F), usually as high as 2480 °C (4500 °F), and sometimes as high as 9750 °C (5400 °F), converting carbon to its crystalline allotropic form. Temperature depends on precursor and properties desired.

green strength. The ability of the material (such as a urethane elastomer), while not completely cured, to undergo removal from the mold and handling without tearing or permanent distortion.

greige, gray goods. Any fabric before finishing, as well as any yarn or fiber before bleaching or dyeing; therefore, fabric with no finish or size.

H

hand. The softness of a piece of fabric, as determined by the touch (individual judgment).

hand lay-up. The process of placing (and working) successive plies of reinforcing material or resin-impregnated reinforcement in position on a mold by hand.

handling life. The out-of-refrigeration time over which a material retains its handleability.

hardener. A substance or mixture added to a plastic composition to promote or control the curing action by taking part in it.

hardness. The resistance to surface indentation usually measured by the depth of penetration (or arbitrary units related to the depth of penetration) of a blunt point under a given load using a particular instrument according to a prescribed procedure. See also *Barcol hardness*, *Mohs hardness*, *Rockwell hardness*, and *Shore hardness*.

harness satin. Weaving pattern producing a satin appearance. "Eight-harness" means the warp tow crosses over seven fill tows and under the eighth (repeatedly).

heat-activated adhesive. A dry adhesive that is rendered tacky or fluid by application of

porosity. A condition of trapped pockets of air, gas, or vacuum within a solid material. Usually expressed as a percentage of the total nonsolid volume to the total volume (solid plus nonsolid) of a unit quantity of material.

postcure. Additional elevated-temperature cure, usually without pressure, to improve final properties and/or complete the cure, or decrease the percentage of volatiles in the compound. In certain resins, complete cure and ultimate mechanical properties are attained only by exposure of the cured resin to higher temperatures than those of curing.

postforming. The forming, bending, or shaping of fully cured, C-staged thermoset laminates that have been heated to make them flexible. On cooling, the formed laminate retains the contours and shape of the mold over which it has been formed.

pot life. The length of time that a catalyzed thermosetting resin system retains a viscosity low enough to be used in processing. Also called working life.

power factor. The cosine of the angle between voltage applied and the current resulting. Measurements are usually made at million-cycle frequencies.

PPS. See *polyphenylene sulfide*.

precure. The full or partial setting of a synthetic resin or adhesive in a joint before the clamping operation is complete or before pressure is applied.

precursor. For carbon or graphite fiber, the rayon, PAN or pitch fibers from which carbon and graphite fibers are derived.

prefit. A process for checking the fit of mating detail parts in an assembly prior to adhesive bonding, to ensure proper bond lines. Mechanically fastened structures are sometimes prefitted to establish shimming requirements.

preform. A preshaped fibrous reinforcement formed by distribution of chopped fibers or cloth by air, water flotation, or vacuum over the surface of a perforated screen to the approximate contour and thickness desired in the finished part. Also, a preshaped fibrous reinforcement of mat or cloth formed to the desired shape on a mandrel or mock-up before being placed in a mold press.

preform binder. A resin applied to the chopped strands of a preform, usually during its formation, and cured so that the preform will retain its shape and can be handled.

pregel. An unintentional, extra layer of cured resin on part of the surface of a reinforced plastic. Not related to gel coat.

preheating. The heating of a compound before molding or casting, to facilitate the operation or reduce the molding cycle.

preimpregnation. The practice of mixing resin and reinforcement and effecting partial cure before use or shipment to the user. See also *prepreg*.

premix. A molding compound prepared prior to and apart from the molding operations and containing all components required for molding: resin, reinforcement, fillers, catalysts, release agents, and other ingredients.

premolding. The lay-up and partial cure at an intermediate cure temperature of a laminated or chopped-fiber detail part to stabilize its configuration for handling and assembly with other parts for final cure.

preply. A composite material lamina in the raw-material stage, ready to be fabricated into a finished laminate. The lamina is usually combined with other raw laminae before fabrication. A preply includes a fiber system that is placed in position relative to all or part of the required matrix material to constitute the finished lamina. An organic matrix preply is called a prepreg. Metal matrix preplies include green tape, flame-sprayed tape, and consolidated monolayers.

prepolymer. A chemical intermediate whose molecular weight is between that of the monomer or monomers and the final polymer or resin.

prepreg. Either ready-to-mold material in sheet form or ready-to-wind material in roving form, which may be cloth, mat, unidirectional fiber, or paper impregnated with resin and stored for use. The resin is partially cured to a B-stage and supplied to the fabricator, who lays up the finished shape and completes the cure with heat and pressure. The two distinct types of prepreg available are (1) commercial prepregs, where the roving is coated with a hot melt or solvent system to produce a specific product to meet specific customer requirements; and (2) wet prepreg, where the basic resin is installed without solvents or preservatives but has limited room-temperature shelf life.

press clave. A simulated autoclave made by using the platens of a press to seal the ends of an open chamber, providing both the force required to prevent loss of the pressurizing medium and the heat required to cure the laminate inside.

pressure bag molding. A process for molding reinforced plastics in which a tailored, flexible bag is placed over the contact lay-up on the mold, sealed, and clamped in place. Fluid pressure, usually provided by compressed air or water, is placed against the bag, and the part is cured.

pressure-impregnation-carbonization (PIC). A densification process for carbon-carbon composites involving pitch impregnation and carbonization under high temperature and isostatic pressure conditions. This process is carried out in hot isostatic press (HIP) equipment.

pressure intensifier. A layer of flexible material (usually a high-temperature rubber) used to ensure the application of sufficient pressure to a location, such as a radius, in a lay-up being cured.

pressure-sensitive adhesive. A viscoelastic material that, in solvent-free form, remains permanently tacky. Such material will adhere instantaneously to most solid surfaces with the application of very light pressure.

primer. A coating applied to a surface, before the application of an adhesive, lacquer, enamel, and so forth, to improve the adhesion performance or load-carrying ability of the bond.

printed wiring board. A completely processed conductor pattern, usually formed on a stiff, flat base (laminated plastic). It serves as a means of electrical interconnection and physical attachment for printed circuits. Also called printed circuit board.

processing window. The range of processing conditions, such as stock (melt) temperature, pressure, shear rate, and so on, within which a particular grade of plastic can be fabricated with optimum or acceptable properties by a particular fabricating process, such as extrusion, injection molding, sheet molding, and so forth. The processing window for a particular plastic can vary significantly with design of the part and the mold, with the fabricating machinery used, and with the severity of the end-use stresses.

promoter. A chemical, itself a feeble catalyst, that greatly increases the activity of a given catalyst. See also *accelerator*.

proof. To test a component or system at its peak operating load or pressure.

proof pressure. The test pressure that pressurized components shall sustain without detrimental deformation or damage. The proof pressure test is used to give evidence of satisfactory workmanship and material quality.

proportional limit. The greatest stress which a material is capable of sustaining without deviation from proportionality of stress and strain (Hooke's law). It is expressed in force per unit area. See also *elastic limit*.

prototype. A model suitable for use in complete evaluation of form, design, performance, and material processing.

puckers. Areas on prepreg materials where material has locally blistered from the separator film or release paper.

pulp molding. The process by which a resin-impregnated pulp material is preformed by application of a vacuum and subsequently is oven cured or molded.

pultrusion. A continuous process for manufacturing composites that have a constant cross-sectional shape. The process consists of pulling a fiber-reinforcing material through a

elastic deformation. The part of the total strain in a stressed body that disappears upon removal of the stress.

elasticity. That property of materials by virtue of which they tend to recover their original size and shape after removal of a force causing deformation. See also *viscoelasticity*.

elastic limit. The greatest stress a material is capable of sustaining without permanent strain remaining after the complete release of the stress. A material is said to have passed its elastic limit when the load is sufficient to initiate plastic, or nonrecoverable, deformation.

elastic recovery. The fraction of a given deformation that behaves elastically. A perfectly elastic material has an elastic recovery of 1; a perfectly plastic material has an elastic recovery of 0.

elastomer. A material that substantially recovers its original shape and size at room temperature after removal of a deforming force.

elastomeric tooling. A tooling system that uses the thermal expansion of rubber materials to form composite parts during cure.

electrical dissipation factor. The ratio of the power loss in a dielectric material to the total power transmitted through it; thus, the imperfection of the dielectric. Equal to the tangent of the loss angle.

electroformed molds. A mold made by electroplating metal on the reverse pattern of the cavity. Molten steel may then be sprayed on the back of the mold to increase its strength.

elongation. Deformation caused by stretching. The fractional increase in length of a material stressed in tension. (When expressed as percentage of the original gage length, it is called percentage elongation.)

elongation at break. Elongation recorded at the moment of rupture of the specimen, often expressed as a percentage of the original length.

encapsulation. The enclosure of an item in plastic. Sometimes used specifically in reference to the enclosure of capacitors or circuit board modules.

end. A strand of roving consisting of a given number of filaments gathered together. The group of filaments is considered an "end" or strand before twisting, a "yarn" after twist has been applied. An individual warp yarn, thread, fiber, or roving.

end count. An exact number of ends supplied on a ball of roving.

endurance limit. See *fatigue limit*.

environment. The aggregate of all conditions (such as contamination, temperature, humidity, radiation, magnetic and electric fields, shock, and vibration) that externally influence the performance of an item.

environmental stress cracking (ESC). The susceptibility of a thermoplastic resin to crack or craze when in the presence of surface active agents or other environments.

epichlorohydrin. The basic epoxidizing resin intermediate in the production of epoxy resins. It contains an epoxy group and is highly reactive with polyhydric phenols such as bisphenol A.

epoxide. Compound containing the oxirane structure, a three-member ring containing two carbon atoms and one oxygen atom. The most important members are ethylene oxide and propylene oxide.

epoxy plastic. A polymerizable thermoset polymer containing one or more epoxide groups and curable by reaction with amines, alcohols, phenols, carboxylic acids, acid anhydrides, and mercaptans. An important matrix resin in composites and structural adhesive.

equator. In filament winding, the line in a pressure vessel described by the junction of the cylindrical portion and the end dome. Also called tangent line or point.

ESC. See *environmental stress cracking*.

even tension. The process whereby each end of roving is kept in the same degree of tension as the other ends making up that ball of roving. See also *catenary*.

exotherm. The liberation or evolution of heat during the curing of a plastic product.

extend. To add fillers or low-cost materials in an economy producing endeavor. To add inert materials to improve void-filling characteristics and reduce crazing.

extenders. Low-cost materials used to dilute or extend high-cost resins without extensive lessening of properties. See also *filler*.

extensibility. The ability of a material to extend or elongate upon application of sufficient force, expressed as percent of the original length.

extensional-bending coupling. A property of certain classes of laminates that exhibit bending curvatures when subjected to extensional loading.

extensional-shear coupling. A property of certain classes of laminates that exhibit shear strains when subjected to extensional loading.

extensometer. A mechanical or optical device for measuring linear strain due to mechanical stress.

F

fabricating (fabrication). The manufacture of products from molded parts, rods, tubes, sheeting, extrusions, or other form by appropriate operations, such as punching, cutting, drilling, and tapping. Fabrication includes fastening parts together or to other parts by mechanical devices, adhesives, heat sealing, welding, or other means.

fabric fill face. That side of the woven fabric where the greatest number of the yarns are perpendicular to the selvage.

fabric, nonwoven. See *nonwoven fabric*.

fabric prepreg batch. Prepreg containing fabric from one fabric batch, impregnated with one batch of resin in one continuous operation.

fabric warp face. That side of the woven fabric where the greatest number of the yarns are parallel to the selvage.

fabric, woven. See *woven fabric*.

fairing. A member or structure, the primary function of which is to streamline the flow of a fluid by producing a smooth outline and to reduce drag, as in aircraft frames and boat hulls.

fatigue. The failure or decay of mechanical properties after repeated applications of stress. Fatigue tests give information on the ability of a material to resist the development of cracks, which eventually bring about failure as a result of a large number of cycles.

fatigue life. The number of cycles of deformation required to bring about failures of the test specimen under a given set of oscillating conditions (stresses or strains).

fatigue limit. The stress level below which a material can be stressed cyclically for an infinite number of times without failure.

fatigue ratio. The ratio of fatigue strength to tensile strength. Mean stress and alternating stress must be stated.

fatigue strength. The maximum cyclical stress a material can withstand for a given number of cycles before failure occurs. The residual strength after being subjected to fatigue.

faying surface. The surfaces of materials in contact with each other and joined or about to be joined together.

felt. A fibrous material made up of interlocked fibers by mechanical or chemical action, moisture, or heat. Made from fibers such as asbestos, cotton, glass, and so forth. See also *batt*.

fiber. A general term used to refer to filamentary materials. Often, fiber is used synonymously with filament. It is a general term for a filament with a finite length that is at least 100 times its diameter, which is typically 0.10 to 0.13 mm (0.004 to 0.005 in.). In most cases it is prepared by drawing from a molten bath, spinning, or deposition on a substrate. A whisker, on the other hand, is

S

sandwich constructions. Panels composed of a lightweight core material, such as honeycomb, foamed plastic, and so forth, to which two relatively thin, dense, high-strength or high-stiffness faces or skins are adhered.

satin. A type of finish having a satin or velvety appearance, specified for plastics or composites.

satin weave. See *harness satin*.

S-basis. The S-basis property allowable is the minimum value specified by the appropriate federal, military, Society of Automotive Engineers, American Society for Testing and Materials, or other recognized and approved specifications for the material.

SBS. See *short beam shear*.

scarf joint. A joint made by cutting away similar angular segments on two adherends and bonding the adherends with the cut areas fitted together. See also *lap joint*.

scrim. A low-cost reinforcing fabric made from continuous filament yarn in an open-mesh construction. Used in the processing of tape or other B-stage material to facilitate handling. Also used as a carrier of adhesive, to be used in secondary bonding.

sealant. A material applied to a joint in paste or liquid form that hardens or cures in place, forming a seal against gas or liquid entry.

secant modulus. Idealized Young's modulus derived from a secant drawn between the origin and any point on a nonlinear stress-strain curve. On materials whose modulus changes with stress, the secant modulus is the average of the zero applied stress point and the maximum stress point being considered. See also *tangent modulus*.

secondary bonding. The joining together, by the process of adhesive bonding, of two or more already cured composite parts, during which the only chemical or thermal reaction occurring is the curing of the adhesive itself.

secondary structure. In aircraft and aerospace applications, a structure that is not critical to flight safety.

self-extinguishing resin. A resin formulation that will burn in the presence of a flame but will extinguish itself within a specified time after the flame is removed.

self-skinning foam. A urethane foam that produces a tough outer surface over a foam core upon curing.

selvage. The woven-edge portion of a fabric parallel to the warp.

semicrystalline. In plastics, materials that exhibit localized crystallinity. See also *crystalline plastic*.

separator. A permeable layer that also acts as a release film. Porous Teflon-coated fiberglass is an example. Often placed between lay-up and bleeder to facilitate bleeder system removal from laminate after cure.

set. The irrecoverable or permanent deformation or creep after complete release of the force producing the deformation.

set up. To harden, as in curing of a polymer resin.

S-glass. A magnesium aluminosilicate composition that is especially designed to provide very high tensile strength glass filaments. S-glass and S-2 glass fibers have the same glass composition but different finishes (coatings). S-glass is made to more demanding specifications, and S-2 is considered the commercial grade.

shear. An action or stress resulting from applied forces that causes or tends to cause two contiguous parts of a body to slide relative to each other in a direction parallel to their plane of contact. In interlaminar shear, the plane of contact is composed primarily of resin. See also *shear strength* and *shear stress*.

shear edge. The cutoff edge of the mold.

shear modulus. The ratio of shearing stress to shearing strain within the proportional limit of the material.

shear strain. The tangent of the angular change, caused by a force between two lines originally perpendicular to each other through a point in a body. Also called angular strain.

shear strength. The maximum shear stress that a material is capable of sustaining. Shear strength is calculated from the maximum load during a shear or torsion test and is based on the original cross-sectional area of the specimen.

shear stress. The component of stress tangent to the plane on which the forces act.

sheet molding compound (SMC). A composite of fibers, usually a polyester resin, and pigments, fillers, and other additives that have been compounded and processed into sheet form to facilitate handling in the molding operation.

shelf life. The length of time a material, substance, product, or reagent can be stored under specified environmental conditions and continue to meet all applicable specification requirements and/or remain suitable for its intended function.

shell tooling. A mold or bonding fixture consisting of a contoured surface shell supported by a substructure to provide dimensional stability.

shoe. A device for gathering filaments into a strand, in glass fiber forming.

Shore hardness. A measure of the resistance of material to indentation by a spring-loaded indenter. The higher the number, the greater the resistance. Normally used for rubber materials.

short beam shear (SBS). A flexural test of a specimen having a low test span-to-thickness ratio (for example, 4:1), such that failure is primarily in shear.

short shot. Injection of insufficient material to fill the mold.

shot capacity. The maximum weight of material an injection machine can provide from one forward motion of the ram, screw, or plunger.

shrinkage. The relative change in dimension from the length measured on the mold when it is cold to the length of the molded object 24 h after it has been taken out of the mold.

silicon carbide. Reinforcement, in whisker, particulate, and fine or large fiber, that has application as metal matrix reinforcement because of its high strength and modulus, density equal to that of aluminum, and comparatively low cost. As a whisker or particulate, it gives the composite isotropic properties and is easily machined.

silicone plastics. Plastics based on resins in which the main polymer chain consists of alternating silicon and oxygen atoms, with carbon-containing side groups. Derived from silica (sand) and methyl chlorides and furnished in different molecular weights, including liquids and solid resins and elastomers.

single-circuit winding. A winding in which the filament path makes a complete traverse of the chamber, after which the following traverse lies immediately adjacent to the previous one.

sink mark. A shallow depression or dimple on the surface of an injection-molded part due to collapsing of the surface following local internal shrinkage after the gate seals. An incipient short shot.

sintering. The bonding of powders by solid-state diffusion, resulting in the absence of a separate bonding phase. The process is generally accompanied by an increase in strength, ductility, and, occasionally, density.

size. Any treatment consisting of starch, gelatin, oil, wax, or other suitable ingredient applied to yarn or fibers at the time of formation to protect the surface and aid the process of handling and fabrication or to control the fiber characteristics. The treatment contains ingredients that provide surface lubricity and binding action but, unlike a finish, contains no coupling agent. Before final fabrication into a composite, the size is usually removed by heat cleaning, and a finish is applied.

sizing content. The percent of the total strand weight made up by the sizing; usually deter-

core separation. A partial or complete breaking of the core node bond.

core splicing. The joining of segments of a core by bonding, or by overlapping each segment and then driving them together.

corrosion resistance. The ability of a material to withstand contact with ambient natural factors or those of a particular artificially created atmosphere, without degradation or change in properties. For metals, this could be pitting or rusting; for organic materials, it could be crazing.

count. For fabric, number of warp and filling yarns per inch in woven cloth. For yarn, size based on relation of length and weight.

coupling agent. Any chemical substance designed to react with both the reinforcement and matrix phases of a composite material to form or promote a stronger bond at the interface.

coupon. Usually, a specimen for a specific test, as a tensile coupon.

crack. An actual separation of material, visible on opposite surfaces of the part, and extending through the thickness. A fracture.

crack growth. Rate of propagation of a crack through a material due to a static or dynamic applied load.

crazing. Region of ultrafine cracks, which may extend in a network on or under the surface of a resin or plastic material. May appear as a white band. Often found in a filament-wound pressure vessel or bottle.

creel. A device for holding the required number of roving balls (spools) or supply packages in desired position for unwinding onto the next processing step, that is, weaving, braiding, or filament winding.

creep. The change in dimension of a material under load over a period of time, not including the initial instantaneous elastic deformation. (Creep at room temperature is called cold flow.) The time-dependent part of strain resulting from an applied stress.

creep, rate of. The slope of the creep-time curve at a given time. Deflection with time under a given static load.

crimp. The waviness of a fiber or fabric, which determines the capacity of fibers to cohere under light pressure. Measured by the number of crimps or waves per unit length.

critical length. The minimum fiber length required for shear loading to its ultimate strength by the matrix.

critical longitudinal stress. Applied to fibers, the longitudinal stress necessary to cause internal slippage and separation of a spun yarn. The stress necessary to overcome the interfiber friction developed as a result of twist.

critical strain. The strain at the yield point.

cross-linking. Applied to polymer molecules, the setting-up of chemical links between the molecular chains. When extensive, as in most thermosetting resins, cross-linking makes one infusible supermolecule of all the chains.

cross-linking, degree of. The fraction of cross-linked polymeric units in the entire system.

cross-ply laminate. A laminate with plies usually oriented at 0° and 90° only.

crosswise direction. Crosswise refers to the cutting of specimens and to the application of load. For rods and tubes, crosswise is any direction perpendicular to the long axis. For other shapes or materials that are stronger in one direction than in another, crosswise is the direction that is weaker. For materials that are equally strong in both directions, crosswise is an arbitrarily designated direction at right angles to the lengthwise direction.

crystalline plastic. A polymeric material having an internal structure in which the atoms are arranged in an orderly three-dimensional configuration.

C-scan. The back-and-forth scanning of a specimen with ultrasonics. A nondestructive testing technique for finding voids, delaminations, defects in fiber distribution, and so forth.

C-stage. The final stage in the reaction of certain thermosetting resins in which the material is practically insoluble and infusible. Sometimes referred to as resite. The resin in a fully cured thermoset molding is in this stage. See also *A-stage* and *B-stage*.

cure. To irreversibly change the properties of a thermosetting resin by chemical reaction, that is, condensation, ring closure, or addition. Cure may be accomplished by addition of curing (cross-linking) agents, with or without heat and pressure.

cure cycle. The time/temperature/pressure cycle used to cure a thermosetting resin system or prepreg.

cure monitoring, electrical. Use of electrical techniques to detect changes in the electrical properties and/or mobility of the resin molecules during cure. A measuring of resin cure.

cure stress. A residual internal stress produced during the curing cycle of composite structures. Normally, these stresses originate when different components of a wet lay-up have different thermal coefficients of expansion.

curing agent. A catalytic or reactive agent that, when added to a resin, causes polymerization. Also called hardener.

CVD carbon. See *chemical vapor deposited (CVD) carbon*.

D

dam. Boundary support or ridge used to prevent excessive edge bleeding or resin runout of a laminate and to prevent crowning of the bag during cure.

damage tolerance. A design measure of crack growth rate. Cracks in damage tolerant designed structures are not permitted to grow to critical size during expected service life.

damping. The decay with time of the amplitude of free vibrations of a specimen. See also *hysteresis* and *attenuation*.

daylight. The distance, in the open position, between the moving and fixed tables or the platens of a hydraulic press. In the case of a multiplaten press, daylight is the distance between adjacent platens. Daylight provides space for removal of the molded part from the mold.

debond. A deliberate separation of a bonded joint or interface, usually for repair or rework purposes. Also, an unbonded or nonadhered region; a separation at the fiber-matrix interface due to strain incompatibility. In the United Kingdom, the term often refers to accidental damage. See also *disbond* and *delamination*.

debulking. Compacting of a thick laminate under moderate heat and pressure and/or vacuum to remove most of the air, to ensure seating on the tool, and to prevent wrinkles.

deep-draw mold. A mold having a core that is long in relation to the wall thickness.

deflashing. A finishing technique used to remove the flash (excess, unwanted material) on a plastic molding.

deflection temperature under load. The temperature at which a simple cantilever beam deflects a given amount under load. Formerly called heat distortion temperature.

deformation under load. The dimensional change of a material under load for a specified time following the instantaneous elastic deformation caused by the initial application of the load. See also *cold flow* and *creep*.

degassing. See *breathing*.

degradation. A deleterious change in the chemical structure, physical properties, or appearance of a plastic.

degree of polymerization. Number of structural units, or mers, in the average polymer molecule in a sample measure of molecular weight.

delamination. Separation of the layers of material in a laminate, either local or covering a wide area. Can occur in the cure or subsequent life.

denier. A yarn and filament numbering system in which the yarn number is numerically equal to the weight in grams of 9000 meters.

strand tensile test. A tensile test of a single resin-impregnated strand of any fiber.

strength, compressive. See *compressive strength*.

strength, flexural. See *flexural strength*.

strength, shear. See *shear strength*.

strength, tensile. See *tensile strength*.

strength, wet. See *wet strength*.

strength, yield. See *yield strength*.

stress. The internal force per unit area that resists a change in size or shape of a body. Expressed in force per unit area.

stress concentration. On a macromechanical level, the magnification of the level of an applied stress in the region of a notch, void, hole, or inclusion.

stress-concentration factor. The ratio of the maximum stress in the region of a stress concentrator, such as a hole, to the stress in a similar strained area without a stress concentrator.

stress corrosion. Preferential attack of areas under stress in a corrosive environment, where such an environment alone would not have caused corrosion.

stress crack. External or internal cracks in a plastic caused by tensile stresses less than that of its short-time mechanical strength, frequently accelerated by the environment to which the plastic is exposed. The stresses that cause cracking may be present internally or externally or may be combinations of these stresses. See also *crazing*.

stress cracking. The failure of a material by cracking or crazing some time after it has been placed under load. Time-to-failure may range from minutes to years. Causes include molded-in stresses, postfabrication shrinkage or warpage, and hostile environment.

stress, fracture. See *fracture stress*.

stress, initial (instantaneous). See *initial (instantaneous) stress*.

stress, nominal. See *nominal stress*.

stress, normal. See *normal stress*.

stress relaxation. The decrease in stress under sustained, constant strain. Also called stress decay.

stress, relaxed. See *relaxed stress*.

stress, residual. See *residual stress*.

stress, shear. See *shear stress*.

stress-strain. Stiffness at a given strain.

stress-strain curve. Simultaneous readings of load and deformation, converted to stress and strain, plotted as ordinates and abscissae, respectively, to obtain a stress-strain diagram.

stress, tensile. See *tensile stress*.

stress, torsional. See *torsional stress*.

stress, true. See *true stress*.

structural adhesive. Adhesive used for transferring required loads between adherends exposed to service environments typical for the structure involved.

structural bond. A bond that joins basic load-bearing parts of an assembly. The load may be either static or dynamic.

superplastic forming (SPF). A strain rate sensitive metal forming process that uses characteristics of materials exhibiting high elongation-to-failure.

surface preparation. Physical and/or chemical preparation of an adherend to make it suitable for adhesive bonding.

surface resistivity (electrical). The surface resistivity of a material is the ratio of the potential gradient parallel to the current along its surface to the current per unit width of surface. Surface resistivity is numerically equal to the surface resistance between opposite sides of a square of any size when the current flow is uniform.

surface treatment. A material (size or finish) applied to fibrous material during the forming operation or in subsequent processes. For carbon fiber surface treatment, the process used to enhance bonding capability of fiber to resin.

surfacing mat. A very thin mat, usually 180 to 510 μm (7 to 20 mil) thick, of highly filamentized fiberglass, used primarily to produce a smooth surface on a reinforced plastic laminate, or for precise machining or grinding.

symmetrical laminate. A composite laminate in which the sequence of plies below the laminate midplane is a mirror image of the stacking sequence above the midplane.

syntactic foams. Composites made by mixing hollow microspheres of glass, epoxy, phenolic, and so forth, into fluid resins (with additives and curing agents) to form a moldable, curable, lightweight, fluid mass; as opposed to foamed plastic, in which the cells are formed by gas bubbles released in the liquid plastic by either chemical or mechanical action.

T

tabs. Extra lengths of composite or other material at the ends of a tensile specimen to promote failure away from the grips.

tack. Stickiness of an adhesive or filament reinforced resin prepreg material.

tack range. The period of time in which an adhesive will remain in the tacky-dry condition after application to the adherend, and under specified conditions of temperature and humidity.

tangent modulus. The slope of the line at a predefined point on a static stress-strain curve, expressed in force per unit area per unit strain. This is the tangent modulus at that point in shear, tension, or compression, as the case may be. See also *secant modulus*.

tape. Unidirectional prepreg fabricated in widths up to 305 mm (12 in.) for carbon and 75 mm (3 in.) for boron. Woven broad goods carbon and glass tapes up to 1250 or 1500 mm (50 or 60 in.) wide are available commercially.

tape wrapped. Fabric tape is heated and wrapped onto a rotating mandrel and subsequently cooled to firm the surface for the next tape layer application.

template. A pattern used as a guide for cutting and laying plies.

tenacity. The term generally used in yarn manufacture and textile engineering to denote the strength of a yarn or of a filament of a given size. Numerically, it is the grams of breaking force per denier unit of yarn or filament size. Grams per denier is expressed as gpd.

tensile modulus. See *Young's modulus*.

tensile strength. The maximum load or force per unit cross-sectional area, within the gage length, of the specimen. The pulling stress required to break a given specimen.

tensile strength, ultimate. See *ultimate tensile strength*.

tensile stress. The normal stress caused by forces directed away from the plane on which they act.

tenth-scale vessel. A filament wound material test vessel based on a one-tenth subscale of the prototype.

terpolymer. A polymeric system that contains three monomeric units.

tex. A unit for expressing linear density equal to the mass or weight in grams of 1000 meters of filament, fiber, yarn, or other textile strand.

textile fibers. Fibers or filaments that can be processed into yarn or made into a fabric by interlacing in a variety of methods, including weaving, knitting, and braiding.

T_g. See *glass transition temperature*.

TGA. See *thermogravimetric analysis*.

thermal conductivity. Ability of a material to conduct heat. The physical constant for the quantity of heat that passes through a unit cube of a substance in unit time when the difference in temperature of two faces is 1°.

thermal endurance. The time at a selected temperature for a material or system of materials to deteriorate to some predetermined level of electrical, mechanical, or chemical

and fusible but may not entirely dissolve or fuse. Also called resistol. The resin in an uncured prepreg or premix is usually in this stage. See also *A-stage* and *C-stage*.

buckling (composite). A mode of failure generally characterized by an unstable lateral material deflection due to compressive action on the structural element involved.

bulk density. The density of a molding material in loose form (granular, nodular, and so forth), expressed as a ratio of weight to volume.

bulk factor. The ratio of the volume of a raw molding compound or powdered plastic to the volume of the finished solid piece produced therefrom. The ratio of the density of the solid plastic object to the apparent or bulk density of the loose molding powder.

bulk modulus. The ratio of the hydrostatic pressure to the volume strain.

bulk molding compound (BMC). Thermosetting resin mixed with strand reinforcement, fillers, and so on, into a viscous compound for compression or injection molding. See also *premix* and *sheet molding compound*.

bundle. A general term for a collection of essentially parallel filaments or fibers.

burned. Showing evidence of thermal decomposition or charring through some discoloration, distortion, destruction, or conversion of the surface of the plastic, sometimes to a carbonaceous char.

burst strength (bursting strength). Measure of the ability of a material to withstand internal hydrostatic or gas dynamic pressure without rupture. Hydraulic pressure required to burst a vessel of given thickness.

bushing. An electrically heated alloy container encased in insulating material, used for melting and feeding glass in the forming of individual fibers or filaments. Also, special extra heavy load-carrying short cylinder inserted in bolt or pin holes.

butt joint. A type of edge joint in which the edge faces of the two adherends are at right angles to the other faces of the adherends.

C

calender. To produce a smooth finish and a desired dimensional thickness for sheet material by passing it between sets of pressure rollers.

carbon. The element that provides the backbone for all organic polymers. Graphite is a more ordered form of carbon. Diamond is the densest crystalline form of carbon.

carbon-carbon. A composite material consisting of carbon or graphite fibers in a carbon or graphite matrix.

carbon fiber. Fiber produced by the pyrolysis of organic precursor fibers, such as rayon, polyacrylonitrile (PAN), and pitch, in an inert environment. The term is often used interchangeably with the term graphite; however, carbon fibers and graphite fibers differ. The basic differences lie in the temperature at which the fibers are made and heat treated, and in the amount of elemental carbon produced. Carbon fibers typically are carbonized in the region of 1315 °C (2400 °F) and assay at 93 to 95% carbon, while graphite fibers are graphitized at 1900 to 2480 °C (3450 to 4500 °F) and assay at more than 99% elemental carbon. See also *pyrolysis (of fibers)*.

carbonization. The process of pyrolyzation in an inert atmosphere at temperatures ranging from 800 to 1600 °C (1470 to 2910 °F) and higher, usually at about 1315 °C (2400 °F). Range is influenced by precursor, individual manufacturer's process, and properties desired.

catalyst. A substance that changes the rate of a chemical reaction without itself undergoing permanent change in composition or becoming a part of the molecular structure of the product. A substance that markedly speeds up the cure of a compound when added in minor quantity as compared to the amounts of primary reactants. See also *accelerator*, *curing agent*, *hardener*, *inhibitor*, and *promoter*.

catastrophic failures. Totally unpredictable failures of a mechanical, thermal, or electrical nature.

catenary. A measure of the difference in length of the strands in a specified length of roving as a result of unequal tension. The tendency of some strands in a taut horizontal roving to sag more than the others.

caul plates. Smooth metal plates, free of surface defects, the same size and shape as a composite lay-up, used immediately in contact with the lay-up during the curing process to transmit normal pressure and temperature, and to provide a smooth surface on the finished laminate.

cavity. The space inside a mold in which a resin or molding compound is poured or injected. The female portion of a mold. That portion of the mold that encloses the molded article (often referred to as the die). Depending on the number of such depressions, molds are designated as single cavity or multiple cavity.

cell. In honeycomb core, a cell is a single honeycomb unit, usually in a hexagonal shape.

cell size. The diameter of an inscribed circle within a cell of honeycomb core.

centrifugal casting. A production technique for fabricating cylindrical composites, such as pipe, in which composite material is positioned inside a hollow mandrel designed to be heated and rotated as resin is cured.

ceramic. A rigid, frequently brittle material made from clay and other inorganic, nonmetallic substances and fabricated into articles by sintering, that is, cold molding followed by fusion of the part at high temperature.

cermet. Composite materials consisting of two constituents, one being either an oxide, carbide, boride, or similar inorganic compound, and the other a metallic binder.

C-glass. A glass with a soda-lime-borosilicate composition that is used for its chemical stability in corrosive environments.

chain length. The length of the stretched linear macromolecule, most often expressed by the number of identical links.

chalking. Dry, chalklike appearance of deposit on the surface of a plastic.

Charpy impact test. A test for shock loading in which a centrally notched sample bar is held at both ends and broken by striking the back face in the same plane as the notch.

charring. The heating of a composite in air to reduce the polymer matrix to ash, allowing the fiber content to be determined by weight.

chemical vapor deposited (CVD) carbon. Carbon deposited on a substrate by pyrolysis of a hydrocarbon, such as methane

chemical vapor deposition (CVD). Process used in manufacture of several composite reinforcements, especially boron and silicon carbide, in which desired reinforcement material is deposited from vapor phase onto a continuous core, for example, boron on tungsten wire (core).

chromatography. See *thin-layer chromatography*.

circuit. In filament winding, one complete traverse of a winding band from one arbitrary point along the winding path to another point on a plane through the starting point and perpendicular to the axis.

circuit board. A sheet of insulating material laminated to foil that is etched to produce a circuit pattern on one or both sides. Also called printed circuit board or printed wiring board.

circumferential ("circ") winding. In filament wound reinforced plastics, a winding with the filaments essentially perpendicular to the axis (90° or level winding).

clamping pressure. In injection molding and transfer molding, the pressure that is applied to the mold to keep it closed in opposition to the fluid pressure of the compressed molding material.

closure. The complete coverage of a mandrel with one layer (two plies) of fiber. When the last tape circuit that completes mandrel coverage lays down adjacent to the first without gaps or overlaps, the wind pattern is said to have "closed."

two layers of prepreg in a cured component do not adhere to each other. Also used to denote specific areas deliberately prevented from bonding in order to simulate a defective bond, such as in the generation of quality standards specimens.

undercure. A condition of the molded article resulting from the allowance of too little time and/or temperature or pressure for adequate hardening of the molding.

undercut. A protuberance or indentation that impedes the withdrawal of a molded part from a two-piece, rigid mold. Any such protuberance or indentation, depending on the design of the mold.

uniaxial load. A condition whereby a material is stressed in only one direction along the axis or centerline of component parts.

unidirectional laminate. A reinforced plastic laminate in which substantially all of the fibers are oriented in the same direction.

unsaturated compounds. Any compound having more than one bond between two adjacent atoms, usually carbon atoms, and capable of adding other atoms at that point to reduce it to a single bond.

unsymmetric laminate. A laminate having an arbitrary stacking sequence without midplane symmetry.

urethane plastics. Plastics based on resins made by condensation of organic isocyanates with compounds or resins that contain hydroxyl groups. The resin is furnished as two component liquid monomers or prepolymers that are mixed in the field immediately before application. A great variety of materials are available, depending upon the monomers used in the prepolymers, polyols, and the type of diisocyanate employed. Extremely abrasion and impact resistant. See also isocyanate plastics and polyurethane.

UV. See *ultraviolet*.

V

vacuum bag molding. A process in which a sheet of flexible transparent material plus bleeder cloth and release film are placed over the lay-up on the mold and sealed at the edges. A vacuum is applied between the sheet and the lay-up. The entrapped air is mechanically worked out of the lay-up and removed by the vacuum, and the part is cured with temperature, pressure, and time. Also called bag molding.

vacuum hot pressing (VHP). A method of processing materials (especially powders) at elevated temperatures and consolidation pressures, and low atmospheric pressures.

vapor-liquid-solid (VLS) process. A process utilizing vapor feed gases and a liquid catalyst, and producing solid crystalline whisker growth. Used to produce silicon carbide whiskers.

veil. An ultrathin mat similar to a surface mat, often composed of organic fibers as well as glass fibers.

vent. A small hole or shallow channel in a mold that allows air or gas to exit as the molding material enters.

vent cloth. A layer or layers of open-weave cloth used to provide a path for vacuum to "reach" the area over a laminate being cured, such that volatiles and air can be removed. Also causes the pressure differential that results in application of pressure to the part being cured. Also called breather cloth.

venting. In autoclave curing of a part or assembly, turning off the vacuum source and venting the vacuum bag to the atmosphere. The pressure on the part is then the difference between pressure in the clave and atmospheric pressure.

vermiculite. A granular material mixed with resin to form a filler of relatively high compressive strength.

VHP. See *vacuum hot pressing*.

vinyl esters. A class of thermosetting resins containing esters of acrylic and/or methacrylic acids, many of which have been made from epoxy resin. Cure is accomplished as with unsaturated polyesters by copolymerization with other vinyl monomers, such as styrene.

virgin filament. An individual filament that has not been in contact with any other fiber or any other hard material.

viscoelasticity. A property involving a combination of elastic and viscous behavior in the application of which a material is considered to combine the features of a perfectly elastic solid and a perfect fluid. Phenomenon of time-dependent, in addition to elastic, deformation (or recovery) in response to load.

viscosity. The property of resistance to flow exhibited within the body of a material, expressed in terms of relationship between applied shearing stress and resulting rate of strain in shear. Viscosity is usually taken to mean Newtonian viscosity, in which case the ratio of shearing stress to the rate of shearing strain is constant. In non-Newtonian behavior, which is the usual case with plastics, the ratio varies with the shearing stress. Such ratios are often called the apparent viscosities at the corresponding shearing stresses. Viscosity is measured in terms of flow in Pa · s (P), with water as the base standard (value of 1.0). The higher the number, the less flow.

VLS process. See *vapor-liquid-solid process*.

void content. Volume percentage of voids, usually less than 1% in a properly cured composite. The experimental determination is indirect, that is, calculated from the measured density of a cured laminate and the "theoretical" density of the starting material.

voids. Air or gas that has been trapped and cured into a laminate. Porosity is an aggregation of microvoids. Voids are essentially incapable of transmitting structural stresses or nonradiative energy fields.

volatile content. The percent of volatiles that are driven off as a vapor from a plastic or an impregnated reinforcement.

volatiles. Materials, such as water and alcohol, in a sizing or a resin formulation, that are capable of being driven off as a vapor at room temperature or at a slightly elevated temperature.

volume fraction. Fraction of a constituent material based on its volume.

volume resistance. The volume resistance between two electrodes in contact with or embedded in a specimen is the ratio between the direct voltage applied to them and that portion of the current between them that is distributed through the volume of the specimen. Also, the electrical resistance between opposite faces of a 1-cm (0.40 in.) cube of insulating material. Also called specific insulation resistance.

vulcanization. A chemical reaction in which a rubber is cured by reaction with sulfur or other suitable agents.

W

wafer. A reinforcement for motorcase port openings.

warp. The yarn running lengthwise in a woven fabric. A group of yarns in long lengths and approximately parallel. A change in dimension of a cured laminate from its original molded shape.

water absorption. Ratio of the weight of water absorbed by a material to the weight of the dry material.

water jet. Water emitted from a nozzle under high pressure (70 to 410 MPa, or 10 to 60 ksi or higher). Useful for cutting organic composites.

weathering. Exposure of plastics to the outdoor environment.

weathering, artificial. See *artificial weathering*.

weave. The particular manner in which a fabric is formed by interlacing yarns. Usually assigned a style number.

weeping. Slow leakage manifested by the appearance of water on a surface.

weft. The transverse threads or fibers in a woven fabric. Those fibers running perpen-

a bondline or encapsulated area; localized, noninterconnected, spherical in shape.

air vent. Small outlet, to prevent entrapment of gases in a molding or tooling fixture.

alkyd plastic. Thermoset plastic based on resins composed principally of polymeric esters, in which the recurring ester groups are an integral part of the main polymer chain, and in which ester groups occur in most cross-links that may be present between chains.

allotropy. The existence of a substance and especially an element in two or more forms (as of crystals). See also *graphite*.

alloy. In plastics, a blend of polymers or copolymers with other polymers or elastomers under selected conditions; for example, styrene-acrylonitrile. Also called polymer blend. In metals, a substance having metallic properties and being composed of two or more chemical elements of which at least one is a metal.

allyl plastic. A thermoset plastic based on resins made by addition polymerization of monomers containing allyl groups; for example, diallyl phthalate (DAP).

alternating stress. A stress varying between two maximum values which are equal but with opposite signs, according to a law determined in terms of the time.

alternating stress amplitude. A test parameter of a dynamic fatigue test: one-half the algebraic difference between the maximum and minimum stress in one cycle.

ambient. The surrounding environmental conditions, such as pressure, temperature, or relative humidity.

amorphous plastic (amorphous phase). A plastic that has no crystalline component. There is no order or pattern to the distribution of the molecules.

anaerobic adhesive. An adhesive that cures only in the absence of air after being confined between assembled parts.

anelasticity. A characteristic exhibited by certain materials in which strain is a function of both stress and time, such that while no permanent deformations are involved, a finite time is required to establish equilibrium between stress and strain in both the loading and unloading directions.

angle-ply laminate. A laminate having fibers of adjacent plies oriented at alternating angles.

angle wrap. Tape fabric wrapped on a starter dam mandrel at an angle to the centerline.

anisotropic. Not isotropic. Exhibiting different properties when tested along axes in different directions. See also *anisotropy of laminates*.

anisotropic laminate. One in which the properties are different in different directions.

anisotropy of laminates. The difference of the properties along the directions parallel to the length or width of the lamination planes and perpendicular to the lamination.

annealing. In plastics, heating to a temperature at which the molecules have significant mobility, permitting them to reorient to a configuration having less residual stress.

antioxidant. A substance that, when added in small quantities to the resin during mixing, prevents its oxidative degradation and contributes to the maintenance of its properties.

antistatic agents. Agents that, when added to a molding material or applied to the surface of the molded object, make it less conducting, thus hindering the fixation of dust or the build-up of electrical charge.

aramid. A type of highly oriented organic material derived from polyamide (nylon) but incorporating aromatic ring structure. Used primarily as a high-strength high-modulus fiber. Kevlar and Nomex are examples of aramids.

arc resistance. Ability to withstand exposure to an electric voltage. The total time in seconds that an intermittent arc may play across a plastic surface without rendering the surface conductive.

areal weight. The weight of fiber per unit area (width × length) of tape or fabric.

aromatic. Unsaturated hydrocarbon with one or more benzene ring structures in the molecule.

artificial weathering. The exposure of plastics to cyclic laboratory conditions, consisting of high and low temperatures, high and low relative humidities, and ultraviolet radiant energy, with or without direct water spray and moving air (wind), in an attempt to produce changes in their properties similar to those observed in long-term continuous exposure outdoors. The laboratory exposure conditions are usually intensified beyond those encountered in actual outdoor exposure, in an attempt to achieve an accelerated effect. Also called accelerated aging.

ash content. Proportion of the solid residue remaining after a reinforcing substance has been incinerated (charred or intensely heated).

aspect ratio. The ratio of length to diameter of a fiber.

assembly time. The time interval between the spreading of the adhesive on the adherend and the application of pressure and/or heat to the assembly.

A-stage. An early stage in the polymerization reaction of certain thermosetting resins (especially phenolic) in which the material, after application to the reinforcement, is still soluble in certain liquids and is fusible. Also called resole. See also *B-stage* and *C-stage*.

attenuation. The diminution of vibrations or energy over time or distance. The process of making thin and slender, as applied to the formation of fiber from molten glass.

Audrey. The trade name of some equipment used for dynamic dielectric analysis (DDA).

autoclave. A closed vessel for conducting and completing a chemical reaction or other operation, such as cooling, under pressure and heat.

autoclave molding. A process in which, after lay-up, winding, or wrapping, an entire assembly is placed in a heated autoclave, usually at 340 to 1380 kPa (50 to 200 psi). Additional pressure permits higher density and improved removal of volatiles from the resin. Lay-up is usually vacuum bagged with a bleeder and release cloth.

automatic mold. A mold for injection or compression molding that repeatedly goes through the entire cycle, including ejection, without human assistance.

automatic press. A hydraulic press for compression molding or an injection machine that operates continuously, being controlled mechanically, electrically, hydraulically, or by a combination of any of these methods.

axial strain. The linear strain in a plane parallel to the longitudinal axis of the specimen.

axial winding. In filament-wound reinforced plastics, a winding with the filaments parallel or at a small angle to the axis (0° helix angle). See also *polar winding*.

B

back pressure. Resistance of a material, because of its viscosity, to continued flow when mold is closing.

bagging. Applying an impermeable layer of film over an uncured part and sealing the edges so that a vacuum can be drawn.

bag molding. A process in which the consolidation of the material in the mold is effected by the application of fluid or gas pressure through a flexible membrane.

bag side. The side of the part that is cured against the vacuum bag.

balanced construction. Equal parts of warp and fill in fiber fabric. Construction in which reactions to tension and compression loads result in extension or compression deformations only and in which flexural loads produce pure bending of equal magnitude in axial and lateral directions.

balanced design. In filament-wound reinforced plastics, a winding pattern so designed that the stresses in all filaments are equal.

balanced-in-plane contour. In a filament-wound part, a head contour in which the filaments are oriented within a plane and